Assessment of Deteriorated Concrete Cover by Combined While-Drilling Techniques

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Abstract: The assessment of concrete cover deterioration generally involves the analysis of cores taken from the structure. Nonetheless, monitoring the drilling operation is itself a way to scan the material condition at increasing depth, which comes at no extra cost once the acquisition of samples has been planned. As an example, the feed rate of the cutting tool proved to be a sensitive indicator of the local damage undergone by the structure. On the other hand, hammer drilling small holes is definitely a faster and less invasive alternative for determining the variability of the mechanical properties within the concrete cover. Although this method does not provide an undisturbed material sample, the visual inspection of the remaining hole (voids, delamination cracks, and color changes) and the analysis of the ground-concrete powder (chemo-physical analyses) proved to be a viable alternative to the traditional examination of cores. **DOI: 10.1061/(ASCE)IS.1943-555X.0000049.** *© 2012 American Society of Civil Engineers.*

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Introduction

Most of the external agents having an effect on the durability of concrete structures (freeze-thaw, fire, carbonation, and moisture in presence of alkali-silica reaction) lead to more or less pronounced variations of the material properties within the concrete cover. The assessment of such gradients cannot be easily performed by means of the commonly available nondestructive techniques (NDTs), the objective of which is generally to smooth the effect of the inherent heterogeneities of the material at the scale of the coarse aggregate (Fib 2008). This is also the significant range of most of the deterioration phenomena under consideration.

Despite the possible detriment to the integrity of the structure, a common approach to this problem is based on the extraction of cores, to be examined as they are (by visual observation, color measurement, ultrasonic scan) or to be cut into slices for subsequent laboratory analyses, as in the case of fire damage assessment (LCPC 2005). A number of investigative techniques are available for this latter purpose, involving the mechanical response of each slice [splitting (dos Santos et al. 2002); punching-load compression (Benedetti and Mangoni 2005); dynamic Young's modulus (Dilek and Leming 2007)]; their physical and morphological features (color, microcrack density, porosity, air permeability, petrographic and SEM examinations—Short et al. 2000); and their physicochemical properties (X-ray diffraction, thermal and chemical analyses). The results pertaining to each slice can then be sorted into a profile that depicts the trend within the concrete cover of the property under study.

This wide assortment of inspection techniques paves the way for the implementation of combined methods, in which an improved accuracy is achieved by properly merging different sets of results. Coring a concrete member can itself be considered as a way of scanning the material soundness at increasing depth, which comes at no extra cost after having decided to take samples of the deteriorated concrete.

To date, the potential of monitoring the core cutting process, a well-established practice in geophysical prospection, has not been studied systematically for the assessment of construction materials. On the contrary, several examples of this kind of approach applied to the simple drilling of holes are available in the literature. By means of suitably modified drills, different operational parameters can be surveyed, such as the thrust or the torque to be exerted to keep a constant feed rate (Chagneau and Levasseur 1989) and the mechanical work expended for a unit penetration of the bit (Felicetti 2006). The attractive benefits of this technique are the little time required to run a test, the immediate availability of the results, and the limited damage to the inspected member. Compared to the core extraction, the main limitation is the lack of a material sample to be submitted to further analyses, though the remaining hole and the ground-concrete powder could in principle be the object of additional investigations.

In this paper, a comparison among some drilling and coring resistance indicators is first carried out to ascertain the sensitivity of these methods to a steep gradient of mechanical properties. Then the potential of the visual observation of the drilled hole and the analysis of the resulting powder are checked as a way to implement the combination of different assessment techniques even in the absence of an undisturbed concrete sample.

Coring and Drilling Resistance

To monitor the process of cutting a concrete core, a common core drill has been fitted with a set of sensors for measuring the rotational speed, the longitudinal stroke, the exerted thrust, and the electric power consumption [Fig. 1(a)].

One significant parameter that can be worked out for ascertaining the quality of the material is the time taken for a unit advance of the tool (s/mm). Though very simple to determine, this value is

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core bits geometry

#	Ø$_{int}$ (mm)	thickn. (mm)	area (mm^2)
1	44	3.5	522
2	54	3.8	680
3	64	3.5	748
4	74	3.5	852
5	100	3.5	1138

exerted thrust

#	thrust (N/mm^2)
a	0.69
b	1.36
c	2.05

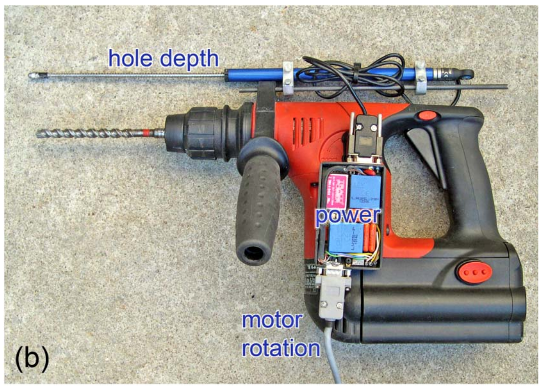


Fig. 1. (a) The core drill fitted with sensors for monitoring the operational parameters and variables investigated in the preliminary tests; (b) modified hammer drill for measuring the drilling resistance (as described in Felicetti 2006)

expected to be markedly influenced by the exerted thrust and the peripheral speed of the cutting tool. As an alternative, the net work spent per unit notched volume (J/mm^3) can be calculated. To do this, the power input is continuously monitored, after balancing the measuring system so to neglect the influence the idle power consumption of the core drill itself. The net power is then multiplied by the drilling time ($W \times s/mm = J/mm$) and divided by the cross-section area of the annular cut to obtain the specific drilling work. In principle, the resulting parameter should be less affected by the working variables because any variation of the exerted thrust or the peripheral speed (namely, the bit diameter) has an opposite effect on the power consumption and the drilling time.

The previous considerations have been validated in the first series of tests, in whcih the effects of the bit diameter, exerted thrust, and rotation rate have been studied by coring ordinary concrete cubes [(side = 150 mm; average cube strength $R_{cm} = 50\ N/mm^2$; two repeated tests for each case (Fig. 2)]. As expected, at the reference rotational speed (600 rpm), the results showed a relatively stable specific work consumption for increasing thrust and tool size. On the contrary, a reduction of the drilling time and a concurrent rise of the electrical power input were observed for the most demanding operational conditions. The same trends have been determined for increasing rotational speed to 1,250 rpm.

The discussed core-drilling resistance indicators are also influenced by the type of cutting tool and by its possible damage and wear, to the point that they can be hardly regarded as material properties. This is also the reason for some irregular variations in the otherwise repeatable and consistent test results (see the drop of the drilling time from 54 to 64 mm bit diameter). Nonetheless, these parameters keep their significance in relative terms, and they still allow a comparison between the responses of pristine and damaged concrete under constant operational conditions. In the following series of tests, the slowest rotation and the intermediate thrust ($1.36\ N/mm^2$) have been adopted together with the smallest core bit ($Ø_{int} = 44$ mm), which has the advantage of only a minor damage to the investigated member.

The sensitivity of the two coring resistance indicators to the material deterioration has been ascertained on two sets of cubes, made of an ordinary and a lightweight aggregate concrete (side = 150 mm; average cube strength $R_{cm} = 50\ N/mm^2$; max-aggregate size = 16 mm). The samples have been tested as they were or after being uniformly damaged by way of a slow thermal cycle (T_{max} = 200, 400, 600, and 800°C; heating/cooling rates = 0.5/0.2°C/min; 1 h spell at T_{max}; four repeated tests for each case).

Identical samples from the same batches were used also in other studies to compare the effectiveness of some established NDTs [rebound hammer, ultrasonic pulse velocity, cut and pull out (CAPO) test; Colombo and Felicetti 2007; Fib 2008]. Moreover, a similar method based on the measurement of the drilling resistance (time and work) by means of a modified hammer drill [Fig. 1(b)] has also been thoroughly investigated (Felicetti 2006). A summary of all the results is presented in Fig. 3. For each kind of test, the results are the average of at least three repeated tests (10 in the case of hammer-drilling). In the graphs, the spline smoothing fits through all the

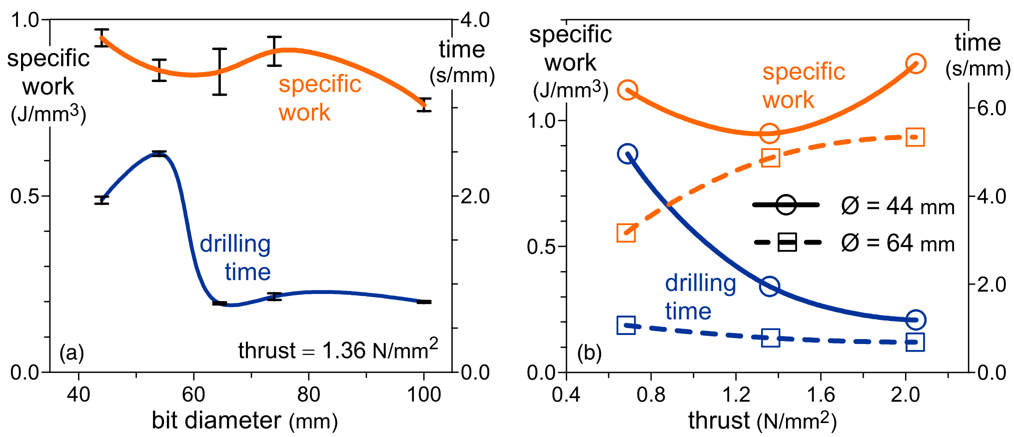


Fig. 2. Results of the preliminary core-drilling tests under varying bit diameter and exerted thrust (rotational speed 600 rpm)

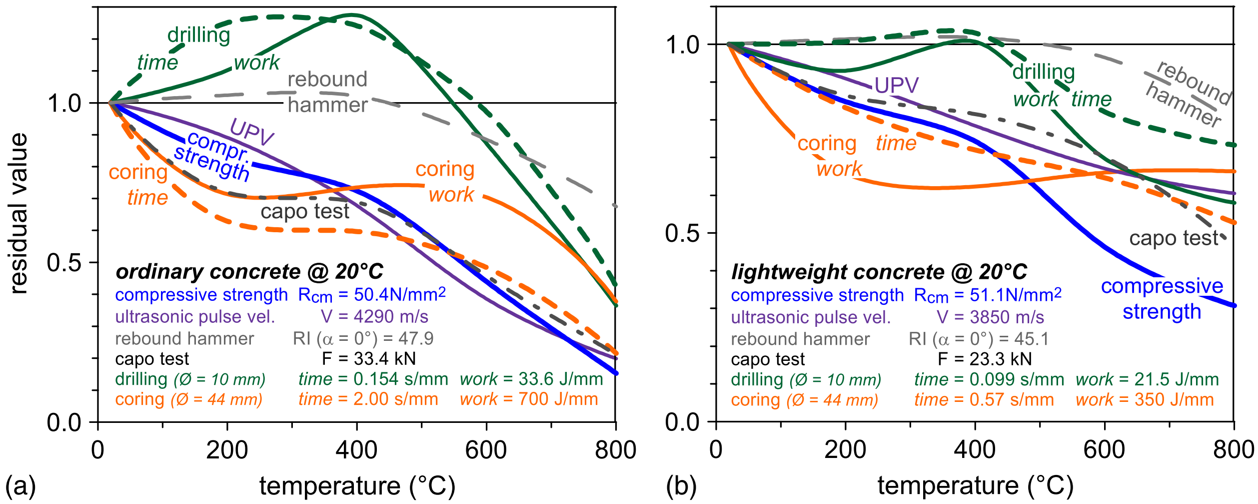


Fig. 3. Sensitivity to a uniform thermal damage of some common NDTs and of the core- and hammer-drilling techniques applied to (a) normal and (b) lightweight concrete

data points at the five reference temperatures, and any non monotonous trend corresponds to the actual experimental observation.

In principle, the coring and the hammer drilling techniques are based on the same microfracturing mechanism induced by a hard indenter scratching the concrete surface. However, the diamond-tipped bit of the core drill is fitted with a number of small hard grains, which have the effect of finely milling the material. The bit of a hammer drill ends with a few large indenters submitted to strong pressure pulses, leading to a deeper propagation of cracks and a coarser fragmentation, especially in stiff and brittle materials like rock and high-grade concrete. Hammer drilling is therefore far less energy demanding than coring, but a rise of both the drilling work and time can be observed in partially damaged concretes (strength decay up to 30%) when the increased deformability and almost constant fracture energy give way to less-efficient penetration mechanisms [plastic crushing and milling rather than chipping (Chiaia 2001)].

For this reason, the dissipated work, the most promising parameter to be monitored in hammer drilling, proved to not be sensitive to moderate levels of damage. On the other hand, the elapsed time is the most responsive parameter in core drilling, provided that a careful control of the exerted thrust is achieved. The fairly good sensitivity to thermal damage of this latter value resembles some well-established NDTs (ultrasonic pulse velocity and capo test) and the trend of the compressive strength itself.

The interesting feature of both of the previously discussed drilling techniques is their ability to continuously scan the material response at increasing depth, even in the presence of strong mechanical property gradients attributable to the concrete cover deterioration. As an example, Fig. 4 reports the profiles recorded while drilling an ordinary concrete panel (thickness = 80 mm) that was initially exposed to a steep thermal gradient. The maximum temperature reached in the panel was determined by means of three embedded thermocouples (depth = 5, 40, and 75 mm) and an almost linear profile was obtained [675–230°C, from left to right (Colombo and Felicetti 2007)]. Based on the temperature at each point and on the calibration curves of Fig. 3(a) (material response versus temperature), the profiles of the expected drilling resistance at each depth have been also worked out for reference. The generally good agreement with the measured profiles confirms the reliability of this approach. Other aspects to be noted are the lower initial resistance attributable to the settlement of the cutting-tools and to the rehydration of the surface concrete, the remarkable sensitivity of the core-drilling time to low damage levels (a 30% decay compared to unheated concrete is recognized already on the cold side of the panel), and the higher influence of the hard aggregate pebbles on the hammer-drilling results, which requires an averaging of some tests to determine a clear trend. In the common case of shallow degradation of relatively thick members, a steady reference value of the resistance is reached at the end of the drilling process

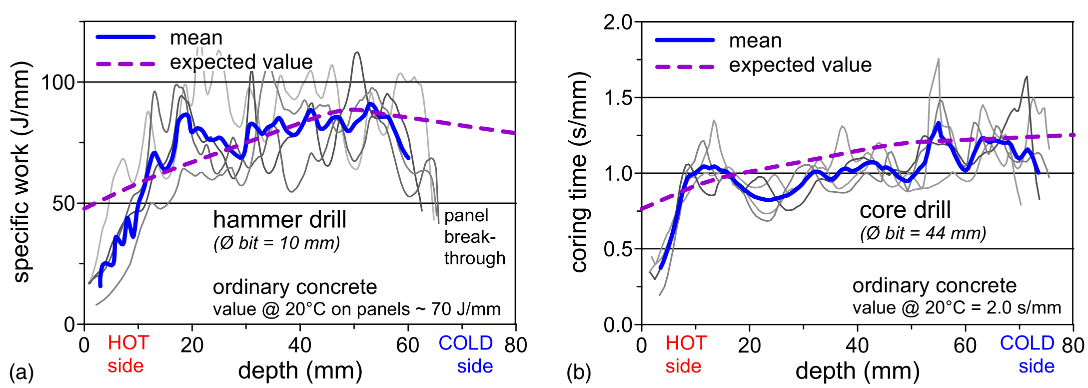


Fig. 4. Profiles of the most responsive (a) drilling and (b) coring resistance indicators for a concrete panel that has been exposed to a steep thermal gradient

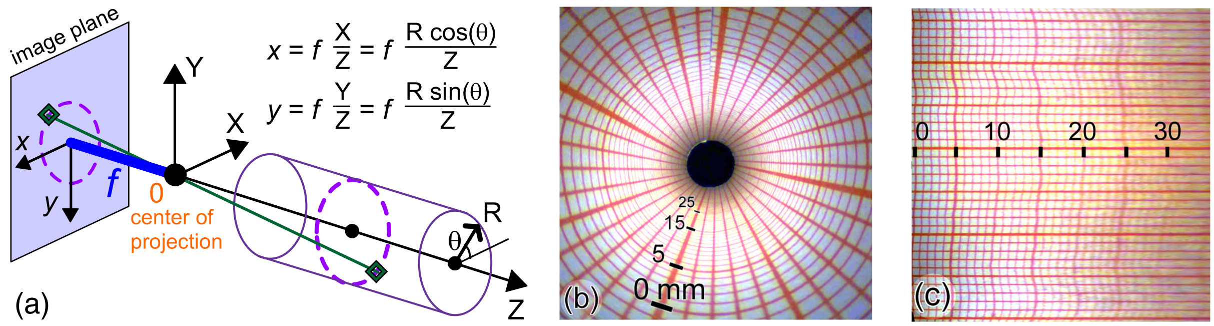


Fig. 5. (a) Endoscopic image projection on the CCD sensor of the digital camera; (b) original view of a rolled graph paper; (c) unwrapped view of a rolled graph paper

when the undeteriorated material is inspected. This allows the profiles to be plotted in relative terms, avoiding the need of specific calibration curves for a first assessment of the damaged depth.

One final remark concerns the viability of the previously discussed drilling techniques for on-site applications. In this regard, hammer drilling is preferable because of the short time required for each test, the little damage caused to the structure, the small operational requirements (no need for water and AC power supply), and the lower instrumentation and labor costs. Its possible combination with further material analyses will be discussed in the following.

Visual Inspection of the Drilled Holes

One advantage of taking cores from a member, compared to hammer drilling, is the opportunity to observe the extracted samples to ascertain the material morphology and condition. Examining the drilled holes through an optical endoscope is an alternative. The limitation of this instrument is to provide a magnified view of just a small portion of the cavity, making it difficult to obtain a complete picture of the inner surface with no influence of the perspective distortion. A number of techniques have been proposed in the literature for the calibration, projection, and merging of the endoscope images, mainly intended for medical and surgical applications.

In this study, a rather simple approach has been implemented to allow a first check on the viability and significance of this kind of observation. The eyepiece of a rigid endoscope with frontal view and a wide field of vision (100°) has been fitted with a digital universal serial bus (USB) camera, to take a series of digital images at regular 10-mm steps. The images are processed to switch from the central perspective to a front view of the unwrapped cylindrical surface of the hole. The transformation is based on the pinhole model of the image projection on the charge-coupled device (CCD) sensor of the camera (Fig. 5) (Trucco and Verri 1998). By assuming a fixed radius of the hole ($R = 5$ mm in this case) and a perfect alignment of the endoscope axis, a simple relationship can be established between the coordinates of the cylindrical surface and the pixels on the image plane.

After having decided on the resolution of the unwrapped image, an array of target coordinates ($R \times \theta_i$, Z_j) is converted into image coordinates (x, y) and the corresponding RGB (red, green, and blue) values are determined from the sampled pixels by means of a cubic-spline interpolation scheme. A proper setting of the focal length f allows to match the longitudinal and the circumferential representation scales, which can be checked on the image of a rolled graph paper [Figs. 5(b) and 5(c)]. Finally, the unwrapped frames are merged by means of software for image editing.

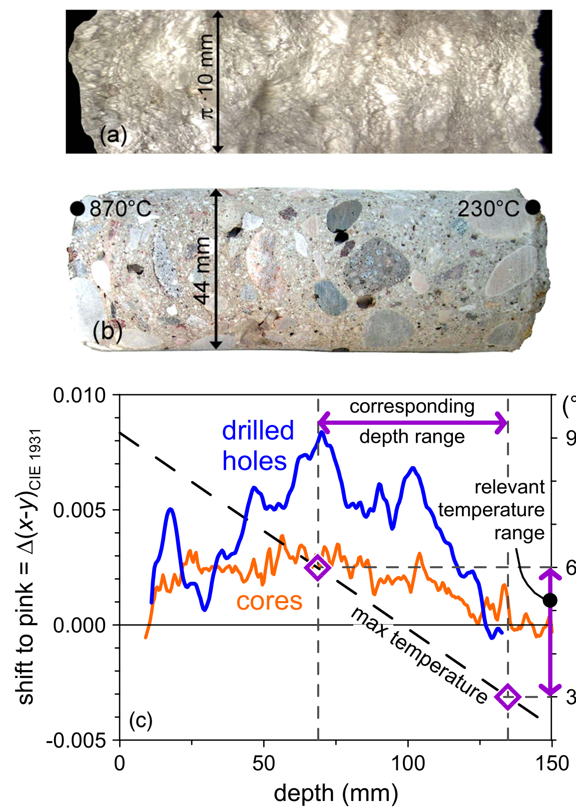


Fig. 6. View of (a) the unwrapped inner surface of a drilled hole and (b) a core taken from the same concrete panel submitted to a thermal gradient; (c) color alteration profiles within the panel determined by means of the digital image analysis

The comparison between the internal image of one hole drilled in a heated concrete panel [Fig. 6(a)] and the side view of a core taken from the same element [Fig. 6(b)] allows to point out the limitations and the potential of this technique. As expected, the limited size of the drilled hole does not allow for the recognition of the material texture or the shape and nature of the coarse aggregate. Moreover, the significant roughness of the hole produced by hammer drilling makes the visual recognition of small pores and flaws quite a difficult task.

Nevertheless, some averaged values can still be measured, such as the slight discoloration occurring along the hole axis. In a former study, the analysis of the digital images of concrete samples has been regarded as a method for detecting the color variations induced by the exposure of concrete to high temperatures

(Felicetti 2005). This technique can be implemented on both kinds of images, though a change of the illuminant generally produces a shift of the chromaticity diagrams [a halogen source and the natural daylight have been used in Figs. 6(a) and 6(b)]. However, the color variation is significant when compared to pristine concrete. Hence, the light source bias can be canceled by zeroing the plots in the depth range pertaining to certainly undamaged material. It can be observed that the analysis of the two kind of images provides comparable trends of the pink discoloration which is expected from heated concrete in the range 300–600°C (Fig. 6(c), averages of two cores and four drilled holes). A greater noise characterizes the results obtained from the drilled holes (standard deviation about 4×10^{-3} versus 6×10^{-4} for the cores), which are also more sensitive to the return to whitish-gray that takes place at higher temperatures (600–900°C).

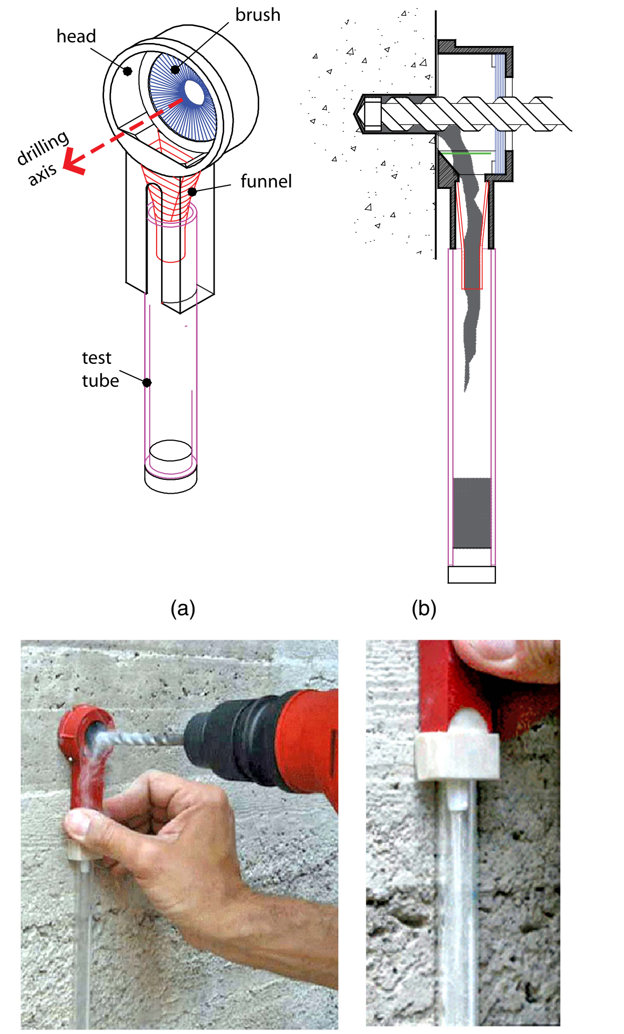
Device for Taking Sorted Samples of Drilling Powder

Several physicochemical analyses on concrete require a preliminary grinding of the material into fine powder (e.g., X-ray diffraction, chloride-ions content, differential thermal analysis (DTA), and thermogravimetric analysis). Moreover, some tests that are normally performed on the intact samples may also be carried out on the pulverized material (e.g., carbonation depth and, color measurement). This evidence casts the base for merging the results of the hammer-drill perforation test and the subsequent examination of the resulting powder. Compared to ordinary laboratory practice, the only limitation is the impracticality of controlling whether or not to include the coarse aggregate in the sample.

In the case of steep variations of the investigated properties with the drilling depth, an important requirement is to preserve the order of extraction to obtain a sorted sample of powder. A special device has been developed specifically for this purpose, which allows the collection of the ground concrete streaming through the helicoidal grooves of the drill bit (Felicetti 2010). Basically, it consists of a annular head with a circular brush to be pierced with the drill bit (Fig. 7). The head is fitted with a funnel, which converges the powder down into a vertical test tube. This can be of transparent material, which will allow for the regular flow of the powder during drilling to be controlled and for a first visual inspection to be performed. A narrow longitudinal cut, thin enough to prevent the particles to pass, makes it possible to infiltrate the sample with the liquid chemicals used in some material analyses (e.g., the phenolphthalein solution for the carbonation-depth measurement).

Some preliminary tests were performed to check the factual sorting of the extracted powder. A number of layered specimens were prepared by gluing plates of different colors [bricks and stones (Fig. 8)]. These plates have been drilled horizontally, and the ensuing powder has been collected in transparent methacrylate pipes. By analyzing the digital images of these samples in the RGB colorimetric space, it is possible to assess quantitatively the pureness of the powder on the basis of its color.

The diagram in Fig. 8 is an example of such representation concerning a calcarenite-brick specimen. For the sake of clarity, the plots have been normalized in the range between 0 (calcarenite) and 1 (brick). The powder keeps a good pureness up to about a 40-mm depth, with a sharp color change at the first layer transition. Then an increasing influence of the lateral scratching of the hole is observed, leading to some mixing between the layers. However, this effect becomes sizeable in a range that is deeper than the cover thickness of most structures, and it can be reduced by improving the alignment of the drill bit.



(a) (b)

(c) (d)

Fig. 7. The device for taking sorted samples of drilling powder: (a) assonometric rear view; (b) vertical section; (c) the device in operation; (d) detail of the powder flowing through the funnel (Italian Patent Application MI2009A 001073, patent pending)

One last aspect to be considered while analyzing these samples is the scale factor between their length and the real depth of the drilled holes. Taking into account the lower apparent density of ground concrete than the intact material, it has been found that a $Ø_{int} =$ 9 mm test tube combined with a 10-mm drill bit yields a scale factor of about 2, improving the sensitivity of the deterioration depth measurements. However, the precise determination of this ratio should be repeated after each sampling.

This device has been recently patented and reengineered, by optimizing the geometry of the different parts and by developing some new details aimed at improving its effectiveness in onsite applications. It is now available as a complete kit for the evaluation of the carbonation depth in concrete structures (Carbontest).

Analysis of the Drilling-Powder Samples

To check the viability of this testing technique, different types of analysis have been performed on the sorted drilling-powder samples (bit diameter = 10 mm). The first example concerns the measurement of the neutralization depth in a set of concrete cubes (side = 100 mm) submitted to an accelerated carbonation process.

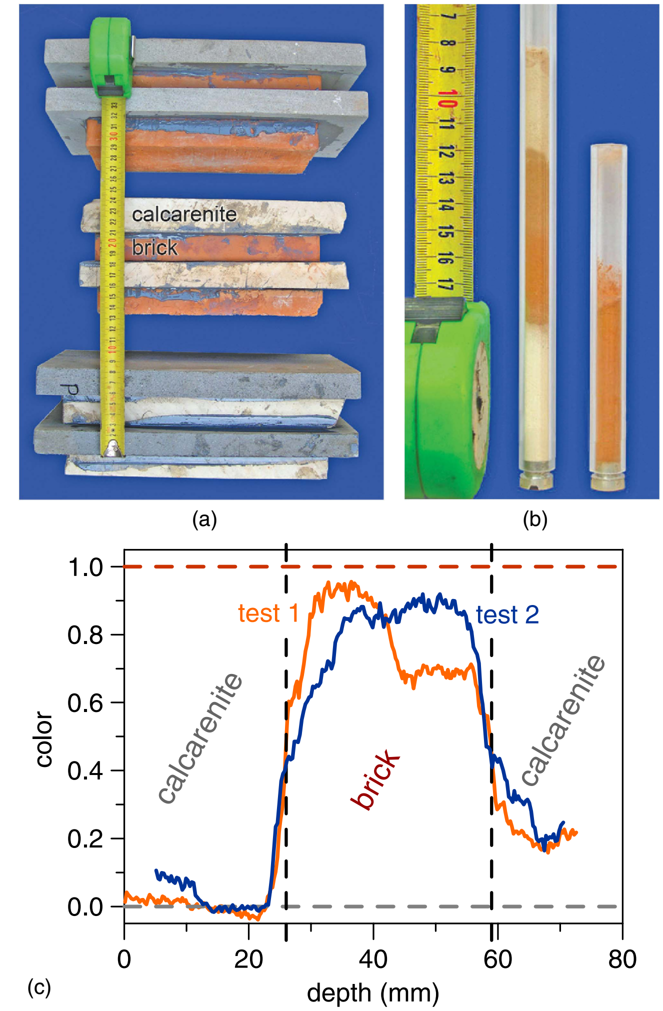


Fig. 8. (a) Layered specimens of alternate colors; (b) powder sample extracted from the central calcarenite-brick specimen; (c) diagrams of the color variations along the powder sample (the abscissa is scaled to the actual depth in the drilled hole)

Some microcores have been cut through the cubes (Ø = 17 mm), and a pH indicator has been applied on their surfaces, highlighting the carbonated zones at the extremities [Fig. 9(a)]. The same reagent has infiltrated the drilling-powder samples by means of the thin longitudinal cut of the dedicated transparent test tubes. In this latter case, the thickness of the carbonated zone must be corrected by the ratio between the hole depth and the sample length (about 2 in this test series).

The results obtained with the two methods [7 and 10 mm at the two ends of the core versus 6 and 8 mm based on the powder samples in Fig. 9(a)] are in reasonably good agreement, if the local irregularities of the carbonation front attributable to the material heterogeneity are considered [Fig. 9(b)]. This latter effect is smoothed down in the powder sample, making the interpretation of the test result easier. The remarkable advantage of the new method is the very short time required (approximately 1 min per test), which makes it feasible to increase the number of the measurement points and to weigh the variability of this kind of deterioration in the case of real structures. One example is provided by the investigation carried out on the unprotected facades of a concrete church [S. Giovanni Bono in Milan, Italy, shown in Fig. 10(a)]. This building dates back to the 1960s and already exhibited durability problems as a result of reinforcement corrosion, as confirmed by a number of obvious repair patches. On the basis of the on-site test results [100 cover thickness measurements and 12 valid tests on powder samples, shown in Figs. 10(b) and 10(c)], it is confirmed that the average depth of carbonation already exceeded the average cover thickness at the time of testing. The former parameter is also characterized by a significantly higher dispersion.

Under the assumption that these variables are governed by independent Gaussian distributions, their difference is also Gaussian, and the probability can be assessed of having passed at any point the initiation period for steel corrosion [namely concrete cover—carbonation depth < 0, as shown in Fig. 10(d)]. In the present case, a 75% probability is worked out, which is consistent with the numerous signs of rebar corrosion of this building. An identical result can been obtained, with no assumptions on the probability distributions, by dividing the depth x in 5-mm classes and applying the following procedure indicated by Pentti and Mattila (COST 2003):

$$\begin{aligned} P_{\text{init}} &= \Sigma_i P_{\text{init}}[x_i < x \leq x_{i+1}] \\ &= \Sigma_i \{P_{\text{cover}}[x_i < x \leq x_{i+1}] \cdot P_{\text{carbonation}}[x \geq (x_i + x_{i+1})/2]\} \end{aligned}$$

where the probability P of either the cover or the carbonation depth to fall in a specific range is determined on the basis of the observed frequencies.

Beside the distinct color variation of the pH indicators, the slight discoloration experienced by concrete exposed to high temperatures can be detected by adopting transparent test tubes. As previously discussed, a proper analysis of the digital images of the powder samples allows the profile of the color shift toward pink to be plotted at increasing depth within a concrete panel exposed

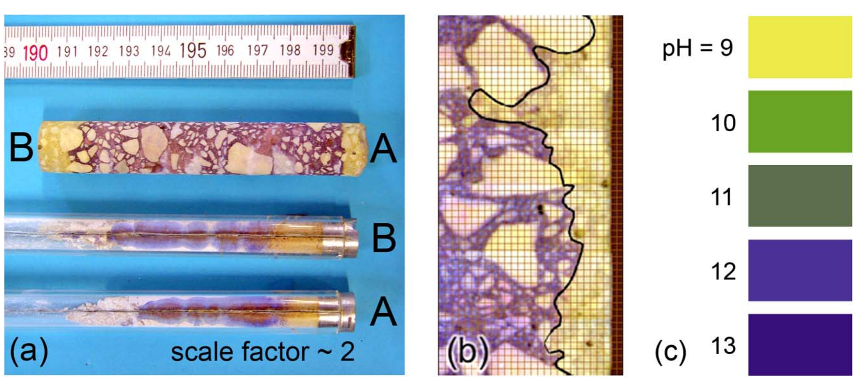


Fig. 9. (a) Carbonation depth in a 100-mm concrete cube, determined on a microcore and on two sorted powder samples; (b) local irregularities of the carbonation front; (c) color scale of the pH indicator

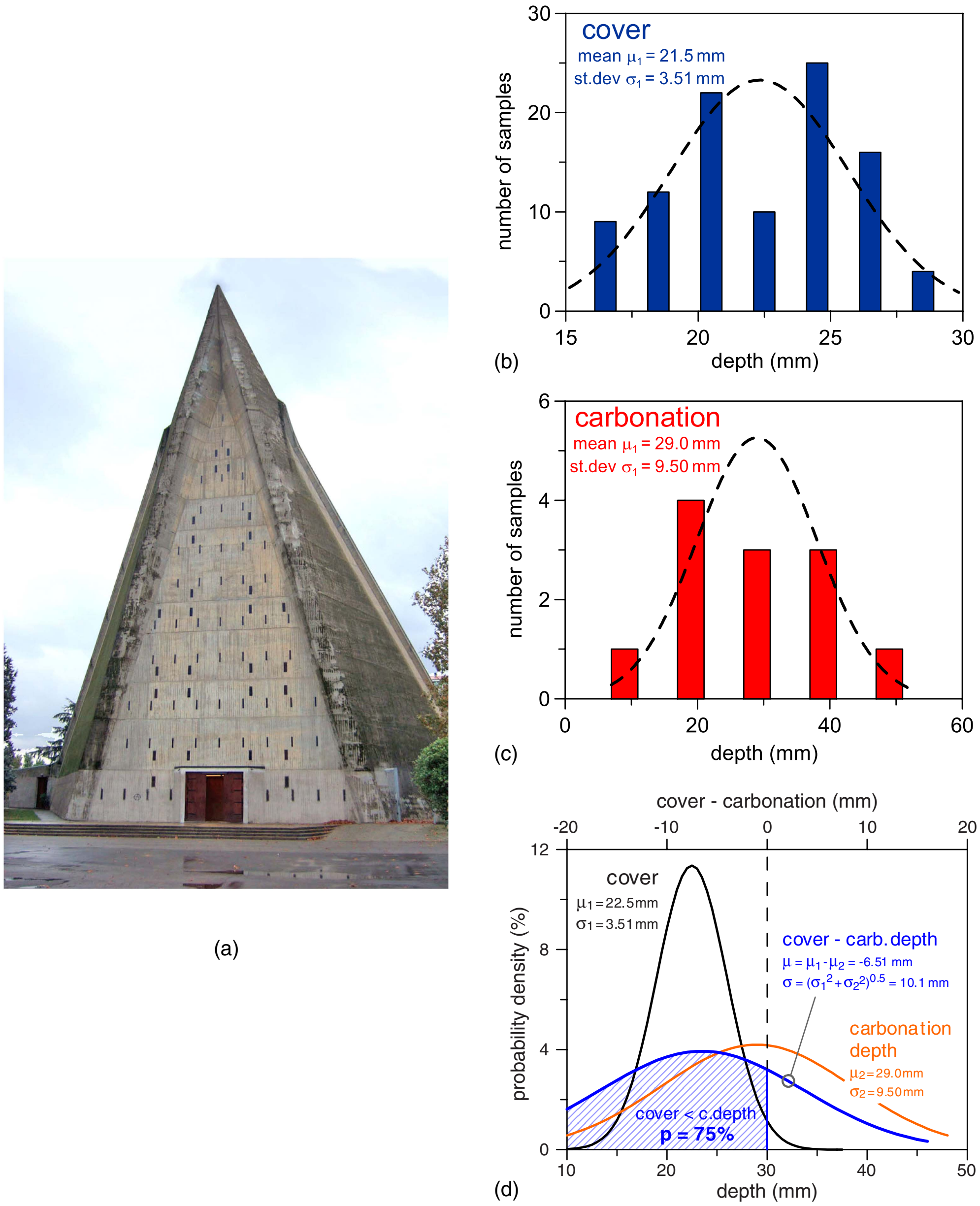


Fig. 10. (a) The S. Giovanni Bono church in Milan; comparison among the frequency distributions of (b) the concrete cover, (c) the carbonation depth, and (d) their difference

to a thermal gradient (Fig. 11). Compared to the conventional analysis of cores, an increased noise level is observed, probably because of the random influence of the coarse aggregate. In the plot of Fig. 11(c), just two single tests are compared, and more reliable results might be obtained by averaging some repeated measurements. Nonetheless, the main features of the material alteration can still be detected in the relevant range from 300 to 600°C [see the analogy between Figs. 11(c) and 6(c)].

The last example regards the differential thermal analysis (DTA), which involves the heating of a small sample of powdered concrete together with a similar amount of inert material (e.g., aluminum oxide). Both samples are monitored to trace their temperature difference, which ensues from the transformations occurring in the tested material. This method has been proposed as a way for analyzing fire-damaged concrete because during this second heating, minor or different transformations occur until the maximum temperature already experienced during the fire is exceeded (Handoo et al. 2002). If a temperature profile through the cover needs to be worked out, the DTA must be repeated on a series of samples taken at increasing depth, which is quite a demanding procedure.

To overcome this limitation, a sorted sample of drilling powder has been collected in a metal pipe by means of the special device described previously. A small amount of aluminum oxide is then added on top of the extracted powder. The pipe [Fig. 12(a)] is made of a thermally stable alloy (nickel chromium), and it is perforated at regular steps along one generatrix to vent the developing gases and to embed a series of thin shielded thermocouples in the inner powder [Fig. 12(b)]. By heating the pipe in a split-tube furnace (5°C/min) several DTAs can be performed at once. Though less rigorous than adopting the standard test procedure and a dedicated device, this method is far less time-consuming and still allows the detection of the onset of the relevant transformations. The first results [Fig. 12(c)] pertaining to the same panel previously mentioned

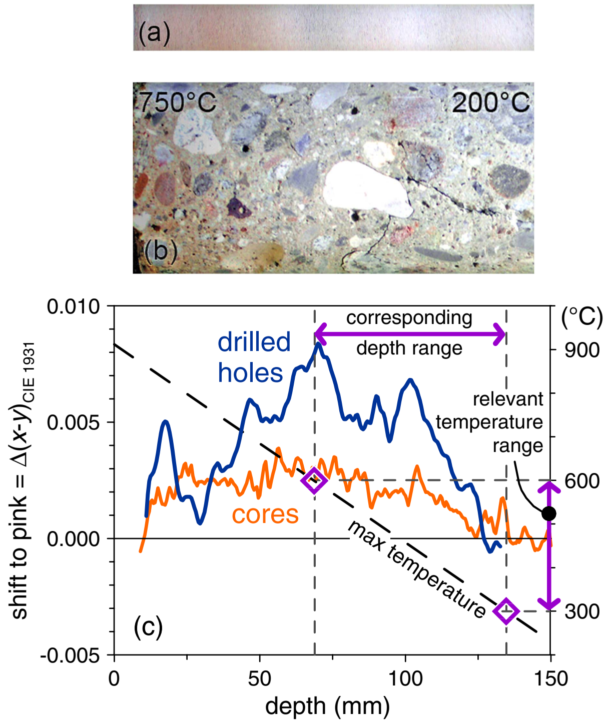


Fig. 11. Discoloration of a powder sample and a core taken from the same heated panel and corresponding color variation profiles obtained by means of the digital image analysis

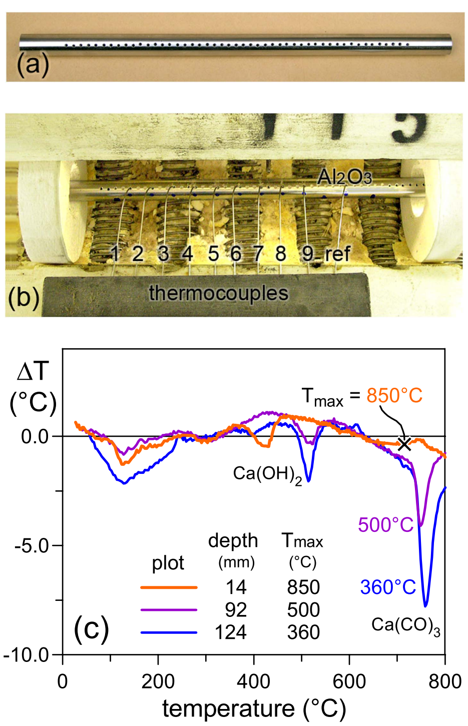


Fig. 12. (a) Nickel-chromium perforated pipe to be filled with a sorted sample of drilling-powder; (b) test setup in the split-tube furnace; (c) temperature differentials pertaining to different depths in a heated panel (see Fig. 6)

in Fig. 6 seem in good agreement with the trends reported in the literature (Alarcon-Ruiz et al. 2005). The anticipated dissociation (compared to unheated portlandite) of the calcium hydroxide resulting from the calcium-oxide rehydration (350–500°C) and the disappearance of the peak ascribable to the calcium-carbonate dissociation (700–800°C) are the main features to trace on these thermodifferential plots.

Conclusions

In this paper, the idea to monitor the resistance encountered while drilling a concrete member and then to analyze the ensuing material has been regarded as a combined method for detecting the possible deterioration of the concrete cover. In this perspective, the well-established practice of analyzing drilled cores can take advantage of this preliminary scan of the material response, which comes at no additional cost once the acquisition of samples has been planned. On the other hand, the faster and less-invasive monitoring of the hammer-drilling resistance, which in principle is not intended to provide any material sample, can be corroborated by the analysis of both the ensuing ground-concrete powder and the remaining hole. The results obtained on these different subjects can be summarized as follows.

- The penetration rate of the core bit at constant exerted thrust is the most responsive parameter to be monitored while drilling a concrete member. The sensitivity is comparable to other effective ND techniques, with the additional benefit of a point-by-point analysis at increasing depth. As concerns the hammer-drilling technique, the energy spent to penetrate the material is the most significant parameter to be surveyed, with the limitation of a poor sensitivity to moderate levels of material damage.
- A valuable support to the visual inspection of the drilled holes is the proper processing of the endoscopic images, aimed to provide an unwrapped front view of the cylindrical surface of the cavity. However, the limited size and the considerable roughness that characterizes the holes produced by hammer drills make the recognition of the material texture and the detection of any small flaws quite a difficult task. Conversely, the analysis of more sketchy features, like the discoloration caused by either the material alteration or the application of chemical indicators, may still compete with the traditional inspection of cores.
- Collecting the powder produced while drilling a concrete member is a convenient alternative to cores in case the laboratory analyses require or allow a preliminary grinding of the material into a fine powder. To this purpose, a special device has been developed to continuously gather the powder streaming out from the hole mouth. The tests concerning the carbonation depth, the color alterations, and the physicochemical response of the material seem to confirm the viability of this method. The only drawback is the impracticality of controlling the effect of the coarse aggregate, the local influence of which may prevail in relatively small drilled holes.

These results are intended as a first check on the viability and significance of the testing techniques proposed in this paper. A systematic study on their reliability will be necessary to factually merge different test results in the assessment of the deteriorated concrete cover.

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