

# Assessment Techniques for the Evaluation of Concrete Structures After Fire

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## ABSTRACT

As concrete structures exposed to fire behave in most cases very well, it could be of economic interest to repair the fire damaged structure. For this purpose a damage assessment based on scientific research is required as first step. In this paper, the Schmidt Rebound Hammer and colorimetry are addressed as tools for this assessment. Firstly, the effect of both methods is studied on heated siliceous concrete specimens under laboratory conditions. Secondly, the practical applicability of both methods is examined by evaluating the fire damage of a concrete girder exposed to a real fire. Both techniques show to be very useful in evaluating the fire damage of the girder.

## 1. INTRODUCTION

Although concrete structures are damaged to a certain extent during a fire, they may retain a residual load bearing capacity [1]. It could therefore be of economic interest to repair the damaged structures, as costs for demolition and rebuilding can be avoided and the building can be reused faster. Different assessment techniques are possible to detect the internal damage after fire, such as Schmidt Rebound Hammer, Ultrasonic Pulse Velocity, Differential Thermal Analysis (DTA), Thermo-gravimetric Analysis (TGA), colorimetry, microcrack-density analysis, petrographic analysis, image analysis, ... It is noticed that most of these techniques are also used to investigate the state of concrete structures at ambient temperatures [2]. A distinction can be made between techniques used in situ and executed under laboratory conditions.

In situ techniques have often the advantage to be direct applicable on the concrete surface in a non-destructive way, for instance to examine the concrete surface hardness, such as Ultrasonic Pulse Velocity or Schmidt Rebound Hammer. These methods allow assessing a large part of the damaged building in a rather short time frame. Although those techniques are quite good to estimate the global fire damage and to distinct the different damaged zones, they can only provide limited information on the depth of fire damage inside the concrete.

On the other hand, laboratory testing demands for a core drilled out of the structure and is useful if the in depth damage needs to be known, for instance required for calculation of the remaining load bearing capacity. The cores can be drilled at the most interesting zones detected with the in situ techniques. On the core, the fire damage can be examined with advanced techniques resulting in the detection of different isotherms. In [3], petrographic analysis is used to detect the degradation of the cement stone at different temperatures, whereas in [4] image analysis is used on scanned images of polished concrete samples to analyse the colour alteration with temperature over the concrete core. The colour changes can also be measured with a spectrophotometer, as is described in [5] for concretes composed of Portland cement in combination with calcareous or siliceous aggregates. Due to heating, also the porosity increases because of cracking and degradation of the cement hydration products.

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Water immersion of concrete samples seems to be a promising technique since it could relate the increase of porosity to the exposed temperature, as is discussed in [5]. Other techniques such as XRD, TGA/DTA and SEM are studied in [2, 6, 7].

This paper contributes to the research as it studies the application of the Schmidt Rebound Hammer and colorimetry as tools to assess the fire damage of concrete structures. Firstly, experimental data is acquired under laboratory conditions on small specimens. Secondly, this information is used to evaluate the damage of a case study consisting of a girder exposed to a real fire. Both techniques show to be very useful in evaluating the fire damage and can provide the necessary information for a calculation of the residual load bearing capacity.

## 2. CONCRETE MIX

In this paper a traditional vibrated concrete with siliceous aggregates and ordinary Portland cement (TC) is studied. For  $1 \text{ m}^3$ , it is composed of 640 kg sand, 525 kg gravel 2–8 mm, 700 kg gravel 8–16 mm, 350 kg cement and 165 litre water. Cubes with size 150 mm were cast and cured for 4 weeks in an air-conditioned room ( $\text{RH} > 90\%$ ,  $20 \pm 1^\circ\text{C}$ ), after which they were stored at 60% RH and  $20 \pm 1^\circ\text{C}$  for drying until further testing. The mean compressive strength at 28 days was  $56.5 \text{ N/mm}^2$ .

## 3. COLORIMETRY

At an age of 3 months, cores with 80 mm diameter and 150 mm height were drilled out of the cubes, sawn in 6 discs, polished and dried till testing time for at least two weeks at  $60^\circ\text{C}$ . Since this was repeated for another cube cast at a later time, a total of 24 discs were obtained. Two discs (belonging to different mixes) were heated without mechanical load at a heating rate of  $30^\circ\text{C}/\text{min}$  to the target temperature (till  $1160^\circ\text{C}$ ), which was kept constant for 1 h. The discs were slowly cooled in the oven, after which they were immediately tested for colour.

The colour was measured with an X-rite SP60 spectrophotometer according to the CIE Lab-colour space. In this colour system 'L\*' is the lightness with values between 0 (black) and 100 (white), while 'a\*' is spread between magenta (positive values) and green (negative values) and 'b\*' is positioned between yellow (positive values) and blue (negative values). The coarse aggregates were masked with black ink to minimize the effect of the colourful aggregates. During heating, the colour described a path in the  $a^*b^*$ -colour space (Fig. 1), which changed from grey at  $20^\circ\text{C}$  to red-pink at  $300\text{--}600^\circ\text{C}$ , to whitish grey at  $600\text{--}900^\circ\text{C}$  and buff at  $900\text{--}1000^\circ\text{C}$ .

Similar colour paths were found from cores drilled out of a heavily heated structure and cut in discs parallel to the fire exposed surface. A comparison of the shape of these paths with Fig. 1 results in the

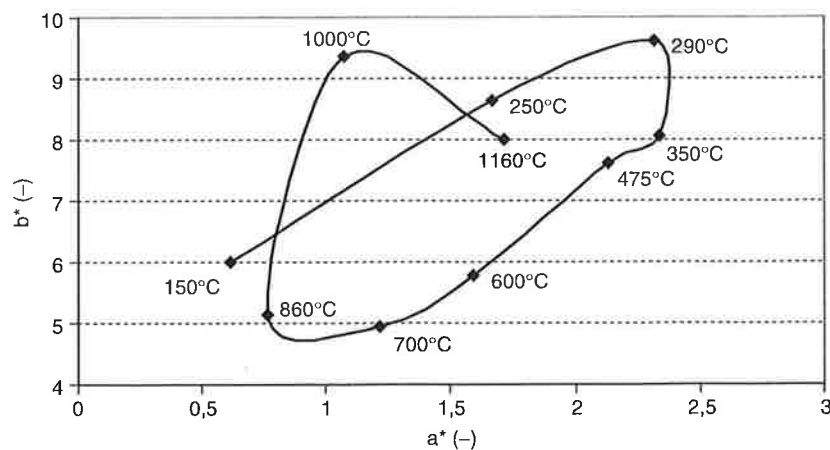


Figure 1. Colour evolution of traditional concrete with masked aggregates.

detection of different isotherms, such as  $\sim 300^{\circ}\text{C}$ ,  $\sim 600^{\circ}\text{C}$ ,  $\sim 800^{\circ}\text{C}$  and  $\sim 1000^{\circ}\text{C}$ . On the other hand, the core can also be sawn in halves along its longitudinal axis. Study of the colour changes along this longitudinal axis would only result in the detection of the  $300^{\circ}\text{C}$  isotherm, since the temperature gradient is steep at the surface layers. Based on the found isotherms, the residual load bearing capacity can be calculated with the methods given in EN 1992-1-2:2004 [8].

#### 4. SCHMIDT REBOUND HAMMER

The Schmidt Rebound Hammer has been used worldwide for many years to detect the surface hardness of a material. Recommendations for the use of the rebound method are given in BS 1881: Part 202 [9], ASTM C805 [10] and NBN EN 12504-2 [11]. Details about this device are given in [12]. The working principle is very simple: when a plunger with a hammer mass is pressed against the concrete surface, a spring is tensioned. At full tension, the spring is automatically released, causing the hammer mass to impact against the concrete. The displayed rebound value of the mass is a measure for the surface hardness of the investigated material.

[9] recommends to take 12 readings over a maximum area of  $300 \times 300 \text{ mm}^2$  with the impact points not less than 20 mm from each other. The rebound index is the mean value of those readings, after leaving out the highest and lowest values. The result gives a measure of the heterogeneity of a surface layer of no more than 30 mm deep, which is for many cases in the neighbourhood of the reinforcement. The higher the rebound index, the stronger and more heterogeneous the investigated material is (less air voids and cracks). For in situ measurements, it is necessary to remove existing plaster in order to obtain the relative hardness of the concrete. Also, the values need to be calibrated, for instance by means of an in situ unheated reference sample.

According to [12], it is not advised to relate the rebound index to compressive strength tests as field experience shows often a bad correlation. To address this problem, EN 13791 [13] proposes to use a basic curve which is linearly shifted according to a calculated value found from at least 9 pairs (both hammer and core compression tests) of test results. Nevertheless, in fire conditions, it is difficult to relate the in-situ found rebound index with the compressive strength from drilled cores. Due to the existing temperature gradient, the rebound index is low at the fire exposed side, but the compression test can take into account less heated concrete layers. This difference will result in bad correlations. The technique can still be used to detect and classify different damaged zones.

The influence of the temperature and storage conditions after fire was tested on half TC cubes heated till uniform temperatures of up to  $600^{\circ}\text{C}$ . The specimens were allowed to cool slowly in the furnace, after which they were stored for 28 days in water or in air (60% R.H.,  $20 \pm 1^{\circ}\text{C}$ ). Fig. 2 depicts the Relative Rebound Index (RRI) tested immediately after cooling (0d) and after 28 days of storage, as well as the compressive strength loss measured on an additional series of heated cubes. RRI is calculated as the percentage of the rebound belonging to a target temperature after a storage period ( $RI_T$ ) divided by the rebound of an unheated reference sample at the beginning of the storage period ( $RI_{20^{\circ}\text{C}}$ ).

It appears that the results at 0 days after heating are close to EN 1992-1-2:2004 and the compressive strength decay of TC cubes (except for the strength drop at about  $100^{\circ}\text{C}$ ). It is noticed that this relationship is found on cubes uniformly heated to the target temperature, therefore the above described in-situ problem about temperature gradient is not applicable. Differences in the evolution of the surface hardness between storage in water and in air are clearly visible. Below  $400^{\circ}\text{C}$ , a higher loss of Rebound Index is noticed for storage in water than in air. On the other hand, beyond  $400^{\circ}\text{C}$ , the surface hardness recovers strongly for specimens stored in water and a further decay is found for air storage. Due to atmospheric effects such as rain and sun, measurements on in-situ structures will be between the extremes as given on the graph.

Based on these results, the following criteria are formulated for the interpretation of the relative rebound index ( $RI_T/RI_{20^{\circ}\text{C}}$ ):

$RI_T/RI_{20^{\circ}\text{C}} > 0.85$	: concrete element is superficially damaged only
$0.85 \geq RI_T/RI_{20^{\circ}\text{C}}$	: concrete element should be further investigated

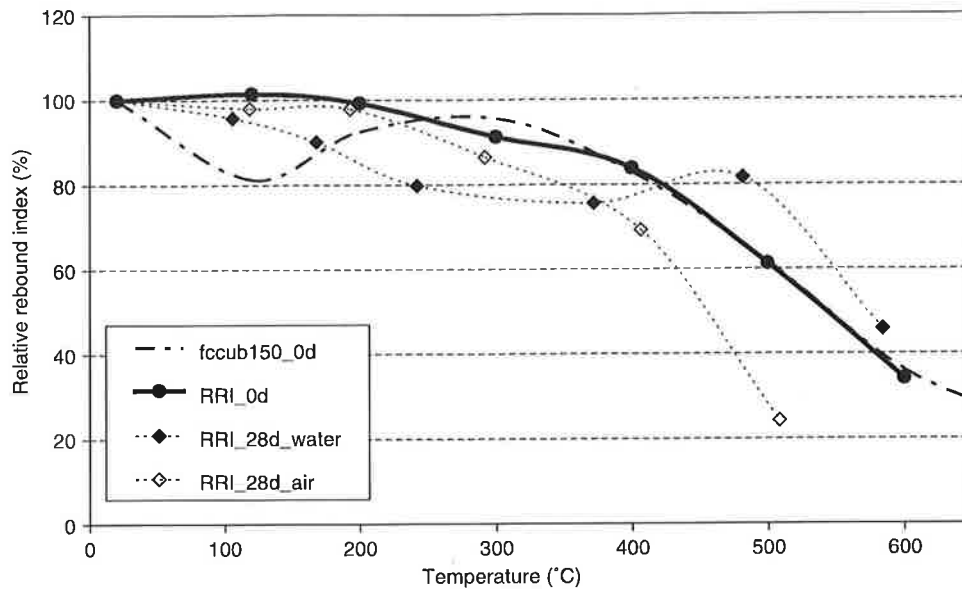


Figure 2. Decrease of Rebound Index as function of temperature and storage conditions for traditional siliceous concrete.

The Schmidt Rebound Hammer can be used as a valuable tool to have a first attempt of the fire damage of concrete elements. Due to its penetration depth of about 30 mm, the degradation of the concrete cover is tested. This degradation is strongly related to the remaining load bearing capacity, since it protects the reinforcement from heating.

## 5. CASE STUDY: FIRE DAMAGE OF A GIRDER FROM AN INDUSTRIAL HALL

### 5.1. Description

In 2010 an industrial hall in Belgium consisting of pretensioned roof girders with a span length of 21 meters has burnt out. The fire started in the paper archive located at a mezzanine, just beneath the girders.

Fig. 3 shows the damage to one of the roof girders. Considering the colour change of the concrete surface, the surface temperature must have been around 900–1000°C. The roof consisted of a composite concrete-steel slab, which was bent towards the fire. The concrete of the girder was spalled over a few centimetres. However, the strands were still covered with concrete and were not directly exposed to the fire. Therefore, it was investigated to which extent the fire damaged had reached the reinforcement. This information is necessary for a calculation of the residual load bearing capacity of the girder.

The concrete cover of a reference girder, located in the neighbouring industrial hall, was 36–40 mm for the stirrups and 45–50 mm for the strands when measured from the side faces with electromagnetic cover detection. From the bottom, the cover was 39–40 mm for the strands.

### 5.2. Results Schmidt Rebound Hammer

Surface hardness readings were performed along the length of the girder, as presented in Tab.1. The test locations are schematically designated in Fig. 4. Locations 1 and 2 were situated at half span length and in the zone with severe fire damage, while location 3 was at 2.5 m of the supports and approximately 4 m from the fire. The relative rebound index is calculated by means of the measurement of a reference girder found in the neighbouring construction with similar properties. It is clear that the fire had influenced the surface hardness ( $RI_T/RI_{20^\circ\text{C}} < 0.85$ ) at locations 1 and 2, while location 3 was not affected.

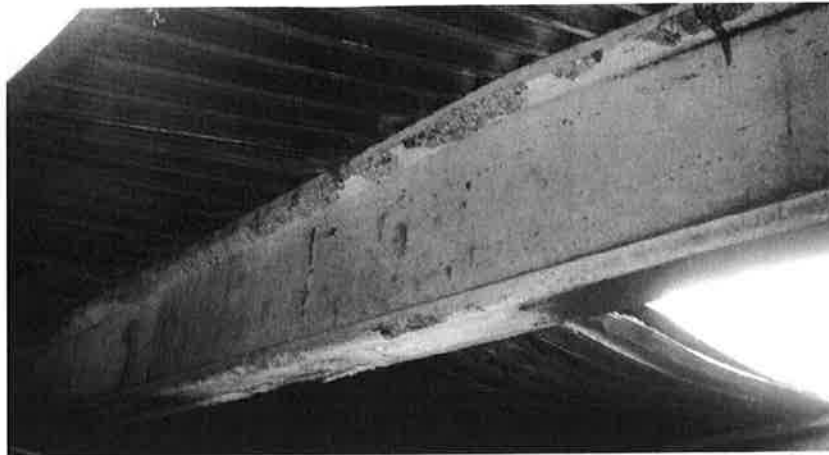


Figure 3. Fire damage of roof girder.

Table 1. Schmidt Rebound Hammer measurements

Test location	Direction of measurement		Average	Standard deviation	$RI_T/RI_{20^{\circ}C}$ [-]
Reference girder	web	side	45.6	2.0	1.00
	flange	side	44.3	2.5	1.00
	flange	bottom	50.9	1.0	1.00
Location 1	web	side 1	36.8	1.8	0.81
	web	side 2	41.2	1.1	0.90
	flange	side 1	30.8	2.3	0.70
	flange	bottom	44.8	1.1	0.88
Location 2	web	side 2	38.0	1.4	0.83
	flange	side 2	30.0	5.7	0.59
	flange	bottom	39.6	1.7	0.78
Location 3	web	side 1	41.0	2.4	0.90
	flange	side 2	44.6	1.3	0.98
	flange	bottom	47.8	4.1	0.94

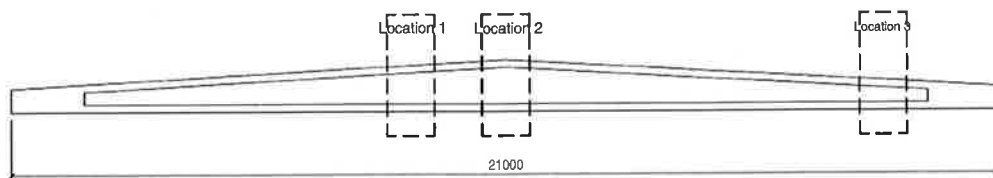


Figure 4. Schematic overview of the Rebound Hammer test locations.

### 5.3. Results Colorimetry

To know the depth of the fire damage inside the concrete, a core was drilled through the web of the exposed girder in the heavily damaged zone. The core had been exposed to fire from both sides. Damage was observed with the naked eye till a depth of 12 mm from one side and 10 mm from the

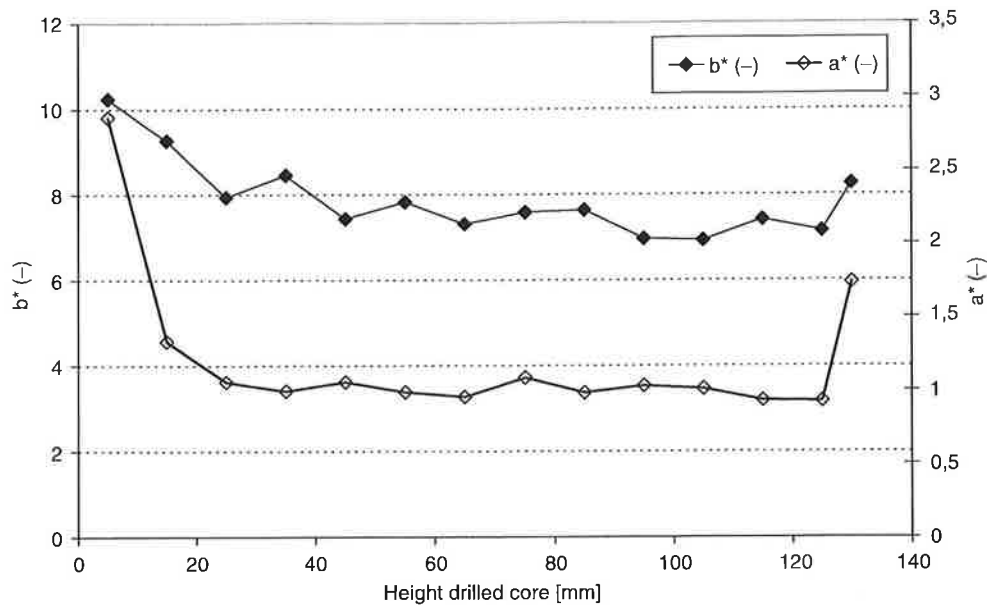


Figure 5. Development of  $a^*$  and  $b^*$  over the body of the girder.

other side. Based on these findings, the zone between 50 and 70 mm was assumed to be not affected by the heat and was taken as reference. From recordings with the spectrophotometer, a fire damaged zone of 25 mm from the first side and 13 mm from the other side could be detected (Fig. 5). The values near to the surface can be related to temperatures of about 300–600°C (based on Fig. 1). These depths of fire damage are below the measured concrete cover thicknesses. Therefore, the reinforcement had not been heated to critical temperatures and the load bearing capacity of the girder should be adequate.

## 6. CONCLUSIONS

- With increasing temperature, the concrete colour described a colour path in the  $a^*b^*$  colour space.
- Experimental laboratory work on half cubes made of traditional siliceous concrete and heated up to 600°C resulted in a critical relative rebound index of 0.85.
- Both Schmidt Rebound Index and colorimetry proved to be useful to detect the extent of fire damage of a concrete girder exposed to a natural fire.
- Although a pretensioned girder was exposed to high temperatures, the remaining bearing capacity is assumed to be sufficient since the strands were not heated.

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## REFERENCES

- [1] Taerwe, L. and Annerel, E., Loading test on a retrofitted pretensioned concrete girder after fire, in: Alexander, M., Beushausen, M.G., Dehn, F. and Moyo, P., eds., *Proceedings of the 2nd International Conference on Concrete Repair, Rehabilitation, and Retrofitting (ICCRRR)*, CRC Press, Cape Town, 2008, 1061–1067.
- [2] Taerwe, L., Bamonte, P., Both, K., Denoël, J.-F., Diederichs, U., Dotreppe, J.-C., Felicetti, R., Fellingner, J., Franssen, J.-M., Gambarova, P.G., Høj, N.P., Lennon, T., Meda, A., Msaad, Y.,

- Ožbolt, J., Periškić, G., Riva, P., Robert, F., Van Acker, A., *fib bulletin 46: Fire Design of Concrete Structures – Structural Behaviour and Assessment, State-of-the art Report, International Federation for Structural Concrete (fib TG 4.3.2)*, FIB, Lausanne, 2008.
- [3] Ingham, J.P., Application of petrographic examination techniques to the assessment of fire-damaged concrete and masonry structures, *Materials Characterization*, 2009, 60, 700–709.
- [4] Annerel, E. and Taerwe, L., Methods to quantify the colour development of concrete exposed to fire, *Construction and Building Materials*, 2011, 25, 3989–3997.
- [5] Annerel, E. and Taerwe, L., Basic Approach for the Diagnosis of Concrete after Fire Exposure, *Journal of Structural Fire Engineering*, 2010, 1(3), 135–143.
- [6] Liu, X., *Microstructural investigation of self-compacting concrete and high-performance concrete during hydration and after exposure to high temperatures*, PhD thesis, Ghent University, 2006.
- [7] Alarcon-Ruiz, L., Platret, G., Massieu, E. and Ehrbacher, A., The use of thermal analysis in assessing the effect of temperature on a cement paste, *Cement and Concrete Research*, 2005, 35, 609–613.
- [8] *EN 1992-1-2: 2004 - Eurocode 2: Design of Concrete Structures – Part 1-2: General Rules – Structural Fire Design*, CEN, Brussels, 2004.
- [9] *BS 1881: Part 202, Recommendations for surface hardness testing by rebound hammer*, British Standards Institution, London.
- [10] *ASTM C805, Rebound number of hardened concrete*, American Society for Testing and Materials, Philadelphia.
- [11] *NBN EN 12504-2, Testing concrete in structures – Part 2 : non-destructive testing – determination of rebound number*, CEN, Brussels, 2001.
- [12] Bungey, J.H., *Testing of concrete in structures, 2nd edition*, Surrey University Press, Glasgow, 1989, 228 pp.
- [13] *EN 13791, Assessment of in-situ compressive strength in structures and precast concrete components*, CEN, Brussels, 2007.

