NDT Methods for the Assessment of Concrete Structures After Fire Exposure

E. Annerel and L. Taerwe

Abstract This paper studies the application of the Schmidt Rebound Hammer and colorimetry as tool 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.

Keywords Colorimetry • Fire • Remaining load bearing capacity • Schmidt rebound hammer • UPV

Introduction

During a fire, concrete structures behave in most cases very well [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 [2]. In this paper the Schmidt Rebound Hammer and colorimetry are applied both at the laboratory level and in a real fire case.

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Concrete Mix

In this paper a traditional vibrated concrete with siliceous aggregates and ordinary Portland cement (TC) is studied. For 1 m³, it is composed of 640 kg sand, 525 kg gravel 2-8 mm, 700 kg gravel 8-16 mm, 350 kg cement and 165 liter water. Cubes with size 150 mm are cast and cured for 4 weeks in an air-conditioned room (RH >90%, 20±1°C), after which they are stored at 60% RH and 20±1°C for drying until further testing. The mean compressive strength at 28 days is 56.5 N/mm².

Colorimetery

At an age of 3 months, cores are drilled out of the cubes, sawn in 6 discs, polished and dried till testing time for at least two weeks at 60°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°C/min to the target temperature (till 1160°C), which was kept constant for 1h. The discs were slowly cooled in the oven, after which they were immediately tested for colour.

The colour is 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 describes a path in the a*b*-colour space (Fig. 1), changing from grey at 20°C to red-pink at 300-600°C, to whitish grey at 600-900°C and buff at 900-1000°C.

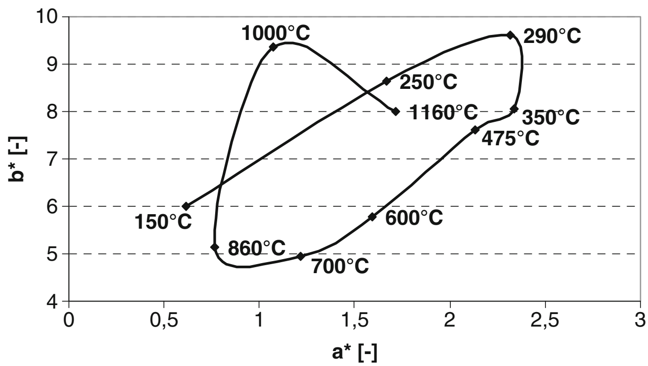

Fig. 1 Colour evolution of traditional concrete with masked aggregates

Similar colour paths can be found from cores drilled out of a heavily heated structure and cut in discs parallel to the fire exposed surface. Comparing the shape of these paths with Figure 1 results in the detection of different isotherms, such as ~300°C, ~600°C, ~800°C, ~1000°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°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.

Schmidt Rebound Hammer

The influence of the temperature and storage conditions after fire are tested on half TC cubes heated till uniform temperatures of up to 600°C. The specimens are allowed to cool slowly in the furnace, after which they were stored for 28 days in water or in air (60% R.H., 20±1°C). Figure 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 ($RI_{20°C}$).

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°C). Differences in the evolution of the surface hardness between

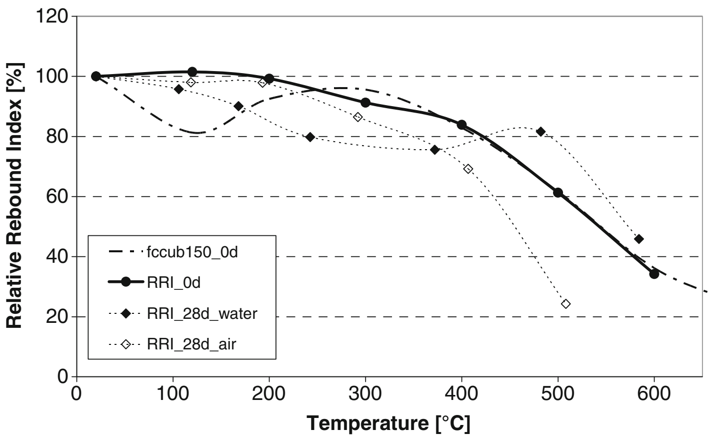

Fig. 2 Decrease of Rebound Index as function of temperature and storage conditions for traditional siliceous concrete

Fig. 3 Fire damage of roof girder

storage in water and in air are clearly visible. Below 400°C, a higher loss of Rebound Index is noticed for storage in water than in air. On the other hand, beyond 400°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 ($RI_T/RI_{20°C}$):

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

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.

Case Study: Fire Damage of a Girder from an Industrial Hall

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 archive located at a mezzanine, just beneath the girders.

Figure 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 consists of a composite concrete-steel slab, which has bent towards the fire. The concrete of the girder has spalled over a few centimetres. However, the strands are still covered with concrete and were not directly exposed

Table 1 Schmidt Rebound Hammer measurements

Test location		Direction of measurement	Average	Standard deviation	$RI_T/RI_{20°C}$ [-]
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	3w9.6	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

to the fire. Therefore, it is investigated to which extent the fire damaged has 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 is 36-40 mm for the stirrups and 45-50 mm for the strands when measured from the side faces. From the bottom, the cover is 39-40 mm for the strands.

Results schmidt rebound hammer

Surface hardness readings are performed along the length of the girder, as presented in Table 1. Locations 1 and 2 are situated at half span length and in the zone with severe fire damage, while location 3 is 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 has influenced the surface hardness ($RI_T/RI_{20°C} < 0.85$) at locations 1 and 2, while location 3 is not affected.

Results colorimetry

To know the depth of the fire damage inside the concrete, a core is drilled through the web of the exposed girder in the heavily damaged zone. The core has been exposed to fire from both sides. Damage is observed with the naked eye till a depth of 12 mm from one side and 10 mm from the other side. Based on these findings, the zone between 50 and 70 mm is assumed to be not affected by the heat and is 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 can be

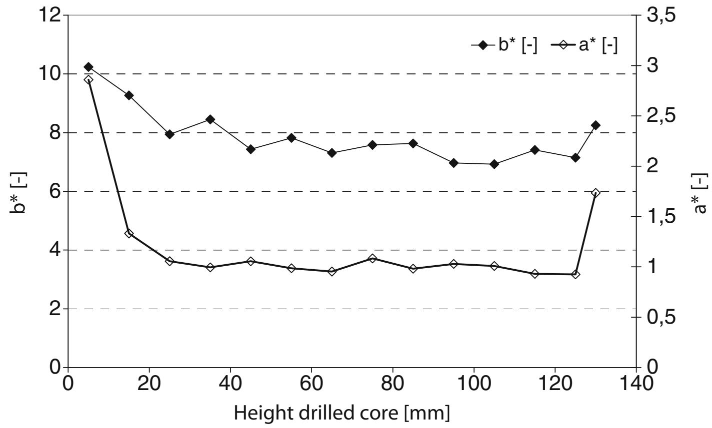

Fig. 4 Development of a* and b* over the body of the girder

detected (Fig. 4). 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 has not been heated to critical temperatures and the load bearing capacity of the girder should be adequate.

Conclusions

- With increasing temperature, the concrete colour describes a colour path in the a*b* colour space.
- Experimental laboratory work results in a critical relative rebound index of 0.85 for siliceous concrete.
- Both techniques 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 are not heated.

References

[1] Taerwe, L. and Annerel, E. (2008), In: Proceedings of the 2nd International Conference on Concrete Repair, Rehabilitation, and Retrofitting (ICCRRR), pp.1061–1067, Alexander, M. et al. (Eds.), CRC Press, Cape Town.
[2] Annerel, E. and Taerwe, L. (2009), *Cem. & Concrete. Res.*, vol. 39, n. 12, p. 1239.