Damage Assessment of Concrete Structures exposed to Fire

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Summary

During a fire, concrete structures behave in most cases very well. 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. To assess the remaining loadbearing capacity in a scientific based way, information is necessary about the temperature distribution inside the concrete element and the residual material properties of both concrete and steel. But, at least of equal importance is a fundamental insight in how a concrete structure could behave during a heating cycle, as indirect actions due to thermal restraints can occur and cause significant cracking. These effects should be noticed during a visual inspection of the structure, however, cracks introduced by internal thermal restraints are not visible from the concrete surface. In this paper, fundamental knowledge is given about the effect of heating and cooling on the compressive strength of concrete. Diagnosis tools are discussed to obtain the temperature distribution, especially in the neighborhood of the reinforcement. Those techniques are based on the physico-chemical transformations of the cement matrix and the aggregates that occur during heating. To determine the effect of thermal restraints on the structural behavior, a methodology based on finite element methods is illustrated.

Keywords: fire, concrete, performance based design, repair, assessment, FEM

1. Physico-chemical transformations and cracking

Concrete is composed of aggregates that are embedded in a cement matrix that is composed of hydration products. When concrete is heated, the hydration products dissociate at different temperatures, resulting in coarsening of the cement matrix. Also, the aggregates suffer from fire damage, but this is strongly depending on the kind of aggregate. Due to heating, the colour of the concrete changes from grey at ambient temperature to red between 300-600°C, whitish grey around 600-900°C and buff at 900-1000°C.

Due to the fire, several cracks are induced in a concrete structures due to differences and restraints of thermal expansion. This is situated at the material level, for example cracking around the aggregates, as well as at the structural level.

2. Assessment techniques

Different techniques are studied to evaluate the strength loss of concrete after fire. These techniques may have a direct relationship with a mechanical property (UPV and Schmidt Rebound Hammer) and/ or are studied in respect to the reached temperature (porosity, colour and petrography). Strength loss can then be found from the degradation curves as function of temperature.

https://doi.org/10.2749/222137813806474417

UPV and Schmidt Rebound Hammer can be used in a non-destructive way, providing additional information to a visual inspection. They are used to scan the highly damaged outer layers of the concrete for surface hardness.

The colour change can be measured with a spectrophotometer. With increasing temperature a colour path is found in the CIE Lab colour space that is shaped like an ellipse.

3. Residual material properties

The residual material properties of concrete exposed to fire are mostly influenced by the cooling rate, the way and duration of post-cooling storage and the existence of external load. Rapid cooling by means of water immersion results in additional cracking and thus strength loss due to a thermal shock. Strength losses of up to 30-35% are found. Because of the further deterioration process during cooling and subsequent storage, the strength is reduced further the first weeks after fire. Strength losses of 15-30% are found during the first 7-21 days after heating. Afterwards, the strength may recover which occurs at a faster rate when stored in water.

Further, the application of load during heating introduces an additional strain type in the concrete, called transient strain. Depending on the load ratio, smaller strength losses are observed, corresponding to smaller strain levels. A constitutive strain model for the behaviour during heating and a full post-cooling stress-strain model based on the Sargin model given in EN 1992-1-1 are developed, taking into account the temperature, the load level and the effects of post-cooling storage in air.

4. Remaining load bearing capacity

Calculating the remaining load bearing capacity of a small pretensioned beam exposed to a natural fire with a simplified calculation methods shows adequate agreement with the experimental data. Extension to this research reveals that for the load bearing capacity after fire probably the use of a 450°C isotherm method would be more appropriate, instead of a 500°C isotherm method.

As discussed above, thermal restraints may induce cracking at the connections of the individual elements or in the concrete mass, that are not visible from the exterior. Such cracking can lead to failure of the structure before the fire resistance as calculated according to EN 1992-1-2 is attained, for instance by shear failure at column tops. Therefore, it is of importance to consider the global structural behaviour and thus the influence of restraint thermal actions, for both design and assessment after fire. Regarding repair after fire, the internal cracks should be located and filled with e.g. an epoxy resin to regain stiffness capacity.

The effect of thermal restraints on the load bearing capacity can be modelled with the method of finite elements by introducing the developed material models. This approach can help to indicate the locations of the hidden cracks.

5. Acknowledgement

The authors would like to thank the Fund for Scientific Research in Flanders (FWO) for the financial support through the research grant “Damage Assessment and Estimation of the Residual Strength of Concrete Members after Exposure to Fire”, as well as IWT Flanders through the research grant “Development of a methodology for diagnosis and repair of concrete structures exposed to fire”.