Determination of the degradation level in fire-damaged RC constructions

A. Dufka & F. Khestl
Brno University of Technology, Faculty of Civil Engineering, Institute of Technology of Building Materials and Components, Veveří 331/95, 602 00, Brno, Czech Republic

ABSTRACT: Degradation of material as a consequence of synergistic action occurs at the fire affected reinforced concrete constructions of both physical (temperature shocks, expansion pressures of water steam etc.), and physically chemical mechanisms (decomposition of cement swage, modification changes in aggregate etc.). With regard to these facts it is obvious that correct judgement of state respectively measure of disruption of constructions interfered this way makes demands on measure of tests and analysis realized in the frame of constructional technical research. The article presented treats problems of diagnostic procedures indispensable for valuable judgement of state of fire-affected constructions.

1 INTRODUCTION

Fire is one of the factors that might be the cause of considerable failure on constructional objects and in extreme cases they might cause the collapse of the whole construction. It is possible to state generally that extreme temperatures connected with the outbreak of fire degraded building materials by contribution of both physical (expansion pressures of water steam, linear respectively volume changes etc.), and physically chemical principles (degradation of material swage, modification changes etc.). This synergy of negative mechanisms will be applied understandably in case of fire affected reinforced concrete constructions.

The fact that reinforced concrete elements are degraded in case of fire by contribution of different principles must be naturally taken into account while choosing diagnostic methods respectively while putting together the conception of constructional technical research whose aim is to judge succinctly the state of building respectively measure of damage caused by fire.

This article is focused on problems with choosing diagnostic procedures that are required for correct judgement of state of reinforced concrete constructions. It is possible to state that these problems (i.e. problems of diagnostic of reinforced concrete constructions affected by fire) are a scientific field that is somehow neglected nowadays by expert public.

One of the key aspects which are indispensable to accept while choosing diagnostic procedures whose aim is to judge the state of constructions affected by fire is taking into account the mechanisms that cause degradation of reinforced concrete. In this chapter, attention is drawn on principles of degradation of reinforced concrete.

2 THE PRINCIPLES OF DEGRADATION OF REINFORCED CONCRETE CONSTRUCTIONS IN ACTION OF EXTREME TEMPERATURES

We can summarise the negative effects in consequence of which failures may occur after the outbreak of fire, possibly entire loss of load-bearing capacity by the following:

Rapid growth in temperature occurs at the outbreak of fire, that is, the surface of construction is exposed to considerable changes of temperature. The speed of growing temperature of construction depends primarily on intensity of fire and character of construction. Destruction of concrete is a consequence of such shocking temperature stress when breaking of the surface concrete layers in thickness up to several centimeters occurs. This kind of failure is called as so-called “blasting of concrete” (spalling). The consequence of this type of failure is among others the fact that the top layer of concrete above the reinforcement was weakened; eventually the reinforcement is exposed to direct action of fire. A considerable heating of reinforcement occurs, accompanied by loss of its bastion, which can threaten in principle the structural analysis of the whole construction.

From the point of view of decrease of physically mechanical parameters of concrete on a basis of Portland cement, which occur as a result of action of higher temperature, the processes that occur in microstructure of cement swage have crucial importance. Mainly these facts are important:

The dehydrating of calciumhydrosilicates respectively calciumhydroaluminates occurs at temperatures up to c. 400ºC. These reactions are to a certain extent reversible. The phases stated above do not create as a rule major binder component of cement stone.

The dissociation of portlandite in cement stone happens in the interval of temperatures 460 until 560ºC. Portlandite is one of the materials that significantly affect binder capabilities of cement stone.

Modification change of silica that as a rule creates the majority part of concrete aggregate (gravel) occurs in temperature of concrete 573ºC. Change of β silica to modification γ that happens at the temperature stated is accompanied by significant volume changes and is therefore a cause of genesis of considerable expansion pressures in the structure of concrete.

The decomposition of compact-grained calcium carbonate (that is, vaterite and aragonite) occurs in approximate range of temperatures 700-820ºC. The dissociation of large-grained calcium carbonate (mainly calcite) occurs in the interval of temperatures c. 820-940ºC. The modification of calcium carbonate belongs to phases that considerably influence adhesive force of cement swage.

It is obvious from the above stated that decrease of mechanical features of concrete exposed to extreme temperatures created by fire is caused by synergic action both physical principles (i.e. destruction as a consequence of "temperature shock") and physically chemical processes that proceed in microstructure of concrete (i.e. decomposition of concrete swage, modification changes in gravel etc.). From the point of view of load-bearing capacity the changes in features of reinforcement respectively decrease of mechanical bond are very important.

Another aspect that can further increase the development of degradation of constructions evaluated is chilling during fire fighting.

3 DIAGNOSTICS OF FIRE AFFECTED CONSTRUCTIONS

In the previous text the fact was stated that mechanisms, which cause the development of degradation on reinforced constructions affected by fire, are not trivial. This reality understandably determines the fact that if the state respectively measure of degradation on reinforced construction affected by fire has to be judged correctly, a complex approach to this problem is indispensable.

A complex of activities whose aim is to judge succinctly the state of fire affected construction respectively judge the measure of degradation on reinforced constructions by extreme temperatures, can be designated as constructional technical research. Methodological approaches applied in the frame of diagnostics of constructions affected by fire, must be understandably adapted to character and state of construction. The following text is looking at the problems.

Visual inspection is a source of initial information about the extent of damage caused by fire and measure of disturbance of individual construction elements. In the frame of visual inspection, the whole state of construction is evaluated primarily, that is, an inquiry is made if some of the elements collapsed, deviation from column is then watched in vertical elements, deflexion was watched in roof girders etc. (gained knowledge this way can be specified geodetically). Furthermore, in the frame of visual inspection, attention is directed on judgement on state of surface of individual elements (destruction of surface layers, presence of breaks etc.), disturbance of decking above reinforcement is watched, measure of bare reinforced steel etc. Gained knowledge in visual inspection enables us to gain source information about damage caused by fire that, understandably, must be completed and expanded in a considerable way for correct judgement of state of construction.

To judge succinctly the state of reinforced constructional elements, in the frame of constructional technical research, determinations are made whose aim is to monitor physically mechanical (that is, especially bastion) and physically chemical (i.e. especially the state of cement swage) parameters of concrete.

3.1 *Physically mechanical parameters of concrete:*

- Determination of compression strength – destructively on core holes (ČSN EN 12390-3) eventually non-destructively (for instance, ČSN 73 1373),
- Determination of bastion of concrete in simple tension (ČSN 73 1318),
- Determination of tensile strength of surface concrete layers (ČSN 73 1318),
- Determination of elongation modulus (ČSN 731371).

3.2 *Physically chemical analysis*

The aim of physically chemical determinations is to judge the state respectively measure of disturbance of cement swage of concrete, eventually to analyse the state of aggregate in concrete. It is possible to use these analyses in advantage for discovering of these facts:

- X-ray diffraction analysis (RTG analysis) – qualitative analysis whose aim is to determine mineralogical composition of swage, eventually aggregate. The procedure of this analysis is defined by methodological approach of VUT FAST in Brno, no. 30-33/1,
- Differential thermal analysis (DTA analysis) – quantitative analysis. Its aim is to quantify especially the volume of phases that create concrete swage. The procedure of this analysis is defined by methodological approach of VUT FAST in Brno, no. 30-33/1.

Another phenomenon that is also monitored in the frame of research of fire-affected constructions is the features of reinforced steel (tensile strength, characteristic strength).

The places for realisation of making tests respectively places of offtake of core holes are chosen as a rule the way that both the localities in which visual inspection proved obvious intensive affection of evaluated elements by fire would be involved and the places in which this disruption is not visible by visual inspection. The aspect applied when judging the state of concrete in separate elements is then comparison of characteristics monitored determined on samples taken in places markedly affected by fire and from constructions in which the traces of action of fire were not obvious.

Another criterion that can be taken into account when judging the state of constructions researched is comparison of features of concrete evaluated with facts declared by project documentation (mainly with declared concrete grade of bastion etc.).

4 THE PROBLEMS THAT COMPLICATE THE INTERPRETATION OF GAINED KNOWLEDGE

Problems of judging of the state of reinforced constructions affected by fire require a complex approach. While judging the state of real constructions, the facts can occur that can significantly complicate the interpretation of gained knowledge in the frame of constructional technical research. The best way will be to document this statement by experience and examples that were gained while evaluating of state of reinforced concrete constructions affected by fire.

We made a constructional technical research of one storey prefabricated reinforced concrete hall, created by prefabricated columns, beams and bearers; membrane roofing was then created by reinforced concrete TT panels.

Figure 1. Fire affected hall.

Gained knowledge at visual inspection stated the fact that most of constructional elements of this hall (that is, columns, bearers and membrane roofing) were quite markedly struck by action of temperatures emerging during fire. A collapse of joining balks and membrane roofing occurred in some parts of the hall.

Figure 2. A collapse of joining balks and membrane roofing.

Some of the joining balks did not collapse entirely, but their deflexion was considerable. There were a lot of cracks on joining balks. In some localities, decking of concrete on joining balks was entirely destructed and reinforcement was disclosed. Membrane roofing was also struck by significant failures.

Figure 3. Local places with totally burned through membrane roofing.

In localities where joining balks collapsed, a collapse of membrane roofing occurred understandably. There were places on columns in which traces of fire were striking, that is, it concerns mainly destruction of decking above the reinforcement. Presence of cracks was also identified on columns. Some of the columns deviated from perpendicular, which could be seen already in visual inspection.

Gained knowledge in visual inspection were naturally completed by a complex of determination both physically mechanical and physically chemical characterisations of concrete. It is possible to summarize this knowledge by the following:

It was found that bastion characterisation of concrete evaluated range in very wide interval.

In localities where intense action of fire was obvious, tensile strength of surface layers was significantly in decrease and in some cases it actually equaled zero.

A rather different situation was found in case of compressive strength. In some elements in which evident traces after massive action of fire were detected by visual inspection, from the point of view of compression strength concrete corresponded with facts noted by project documentation. On the contrary, in some cases the compression strength of concrete was lower than concrete grade of bastion declared by project documentation. From the point of view of judgement of state of separate constructional elements the fact that in some cases decomposition of elements occurred during offtake of core holes was important too. Destruction of core holes was caused by presence of cracks in concrete. In the majority of cases these were cracks that on the surface of construction were only hair cracking, whereas in concrete, which creates the „inner mass“ of the element, their opening was wider. The decomposition of core holes during offtake occurred in some cases as well as when core holes were taken from components in which traces of action of fire were not visible in visual inspection.

The samples of concrete were put through physically chemical determinations that enable them to analyse their composition for judgement of measure of degradation. One of the aspects that were taken into account in evaluation of results of physically chemical analyses was comparison of gained knowledge for separate samples with results of analyses made on sample that was taken off collapsed joining balk, i.e. element that was very strongly affected by fire. It was stated that cement swage is very intensely degraded by action of high temperatures in samples taken off collapsed joining balks. Cement swage of these samples was practically wholly decomposed including phases of calcium carbonate. The modifications of calcium carbonate (calcite, vaterite and aragonite) are minerals that decompose in relatively high temperatures (c. 800 to 950°C). In this case the results of physically chemical analyses proved very intense destruction of cement swage and this fact entirely corresponded with very low bastion of concrete that was found. Intense development of degradation on cement swage by high temperatures was found as well in some other constructional elements. Generally, it can be stated that elements, in which the decomposition of cement swage was found, this fact was accompanied by decrease (and as a rule very considerable) of bastion characterisation of concrete.

Indeed, the results of physically chemical analyses in some of the elements evaluated indicate a relatively low measure of degradation on cement swage by high temperatures, which did not respond to the results of physically mechanical determinations, when a considerable decrease of bastion parameters of concrete was found. This disproportion between gained knowledge by physically chemical analyses and results of tests of bastion characterisation of concrete can be justified be these principles respectively by their synergy:

- In consequence of “temperature shocks” emerging at the outbreak of fire respectively even while putting it out conditions for development and propagation of cracks are created in the structure of concrete. The cracks can also develop as a consequence of cumulation of water steam in the structure of concrete (spalling). The development of cracks can occur even in relatively low temperatures. These cracks do not result in significant changes in mineralogical composition of cement swage.

- The changes happening in aggregate, which creates filler in concrete, also take part in lowering of mechanical parameters of concrete. Aggregate with relatively high volume of silica was used in this case. Modification changes occur in increase of temperatures in this material (change of β silica to γ modification) accompanied by volume changes. However, these processes are reversible, that is, after lowering of temperature silica in modification β dominates absolutely again in the structure of concrete. It is obvious from the stated above that detection whether modification changes in concrete filler occurred as a consequence of fire is (with regard to reversibility of these changes) relatively difficult.
- In action of high temperatures on cement swage decomposition reactions of phases that create this swage occur. It is mainly the decomposition of, for instance, calciumhydrosilicates, ettringite, portlandite, phases of calcium carbonate etc. It was proved that some of these decomposition reactions are reversible in real time horizon. As an example of this fact, we can state repeated creation of portlandite in cement paste exposed in temperatures that go beyond the temperature of dissociation of portlandite.

5 CONCLUSION

This article treats diagnostic processes whose aim is to judge succinctly the state of reinforced concrete constructions struck by fire and especially securing the data for statical judgement of constructions evaluated.

Generally, it can be stated that while monitoring the state of constructions struck by fire, de facto analogical characteristics are watched, as in case of constructional technical research of objects exploitated in "common" conditions. Thus both physically mechanical parameters of concrete are watched (especially its bastion characterisation) and physically chemical analyses are made (with an aim to judge the state of cement swage) and the state of steel reinforcement is monitored as well. It is indispensable to respect mechanisms that caused destruction of reinforced concrete constructions evaluated (i.e. the fact that synergy of physical and physically chemical principles is the cause of creation of failures) for relevant interpretation of gained knowledge by a complex of these tests.

On the basis of knowledge found at evaluating of state of reinforced concrete constructions struck by fire, it is possible to state that one of the phenomenons which significantly take a share in many cases on intense decrease of bastion characterisation of concrete is creation and development of cracks. The creation of cracks is determined mainly by physical principles (as for instance, changes in temperature by shock, expansion pressure by water steam).

Another piece of knowledge which was gained in the frame of diagnostic procedures realised on fire affected constructions, is the fact that the quantity which very precisely describes measure of interference on reinforced concrete element by extreme temperatures, is tensile strength of surface layers of concrete.

Generally, it is possible to state that action of extreme temperatures significantly decreases tensile strength of concrete than compression strength is. This fact is caused by creation of microscopic cracks in cement swage, by creation of defects in the interface of swage – grains of aggregate etc. It is obvious that tensile strength of surface layers is a quantity which describes mainly the state respectively measure of disturbance in full the surface of element evaluated. We recommend unambiguously expanding the results of statement of tensile strength of surface layers of concrete by carrying out tests of concrete tensile strength (tests on core holes) for a more complex judgement of state of constructional elements.

Physically chemical analyses whose results in an effective way complete the gained knowledge by physically mechanical tests are an integral part of complex of analyses realised in research of reinforced concrete constructions struck by fire. It is possible to specify more closely the temperature at which separate elements were exposed and thus formulate an assumption about change of bastion parameters of concrete on a basis of determination of mineralogical composition of cement swage in concrete etc.

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