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POSSIBLE OBSERVATIONS ON CONCRETE AFTER HIGH TEMPERATURE LOADING

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Summary: *Fire can cause damage in concrete structures. The level of damage depends on several factors like maximal temperature, duration of fire, constituents of concrete etc. We have to design buildings for fire and deal with the possible reconstruction after a fire case if it happens. Both require special knowledge and special characterization. For reconstruction purposes it is very important to determine the level of damage and the necessary steps after fire. If the building can be renovated, non-destructive test methods are of high importance in analysis of actual damages. For the analysis of fire damage we applied by laboratory a new test method: the computer tomography (CT) method. The method is applicable because the density and porosity values in function of temperature are changed.*

Keywords: *High temperature, concret, X-ray computer tomography*

1. CONCRETE IN FIRE

Concrete has excellent properties in regards of fire resistance compared with other materials and can be used to shield other structural materials such as steel [1].

Effects of high temperatures on the mechanical properties of concrete have been investigated as early as the 1940s [2]. In the 1960s and 1970s fire research was mainly directed to study the behaviour of concrete structural elements [3]. There was relatively little information on the concrete properties during and after fire [4].

During fire the mechanical characteristics of the concrete are changing. During the cooling process concrete is not able to recover its original characteristics. Deterioration

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of concrete at high temperatures has two forms: (1) local damage in the material itself *(Fig. 1)* and (2) global damage resulting the failure of the elements *(Fig. 2)*.

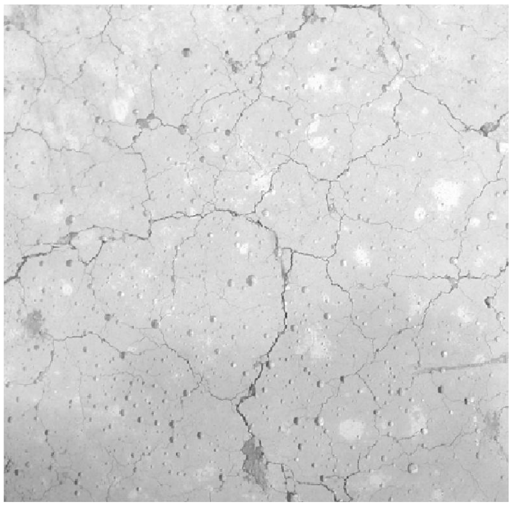

Figure 1. Damage of concrete

Figure 2. Damage of structure [5]

1.1 CONCRETE IN FIRE

Concrete is a composite material, that consists mainly of mineral aggregates bound by a matrix of hydrated cement paste. The matrix is highly porous and contains a relatively large amount of free water unless artificially dried.

When exposed it to high temperatures, concrete undergoes changes in its chemical composition, physical structure and water content. These changes occur primarily in the hardened cement paste in unsealed conditions. Such changes are reflected by changes in the physical and mechanical properties of concrete that are associated with temperature increase. Temperature influences are reflected in changes of physical and mechanical properties of concrete.

Residual compressive strength of concrete exposed to high temperatures is influenced by the following factors [6]:

(1) water to cement ratio,
(2) cement to aggregate ratio,
(3) type of aggregate,
(4) type of cement,
(5) water content of concrete before exposing it to high temperatures and
(6) fire process.

The stress-strain relationship characterizes the stress and deformation capacities of fire exposed concrete *(Fig. 3)*. Test results include a small portion of creep which develops during the stressed period. In case of strain controlled tests with increasing strain, a decrease of stress is observed after the peak stress has been reached [7].

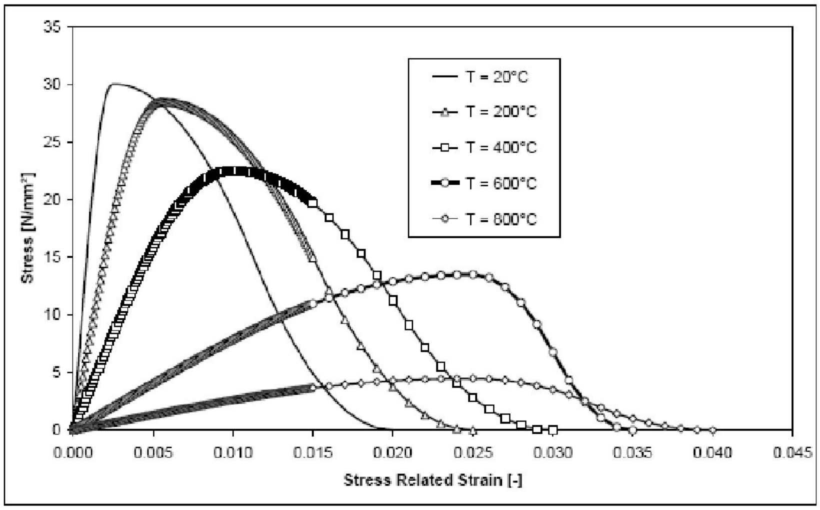

Figure 3. Stress-strain relationship for concrete with quartz gravel aggregate as a function of temperature [8]

2. SPALLING OF CONCRETE COVER

Spalling of concrete cover may have two reasons: (1) internal vapour pressure (mainly for conventional concretes) and (2) overloading of compressed zones (mainly for high strength concretes). Previous experimental observations has been already indicated that the application of synthetic fibres considerably may reduce the probability of spalling of concrete cover. Experiments [9] with tunnel segments (length 11 m, height 2 m) indicated, that the cover of the polypropylene fibre reinforced concrete sections did not spall *(Figs. 4. a and b)*. Utilisation of synthetic fibres do not only reduce the probability of spalling of concrete cover layer, but also reduces the residual compressive strength [10].

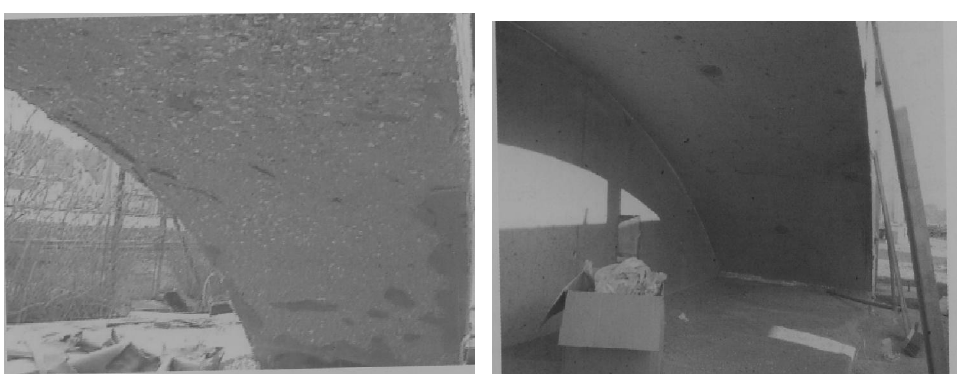

Figure 4. Tunnel segments after exposure to 1200°C temperature [9]
a) without fibre reinforcement, b) with 2 kg/m^3 polypropylene fibre reinforcement

3. LABORATORY TEST

During the laboratory tests the specimens were tempereture loaded in 5 heat steps (20 °C, 50 °C, 150 °C, 300 °C, 500 °C). After heating up to given temperatures the specimens were kept at these maximum temperatures for two hours. Specimens were then cooled down in laboratory conditions. After cooling down the specimens the compressive strength were measured on cylinders (Ø50 mm, h=100 mm) and the flexural strength on beams (70x70x250 mm). The amounts of constituents, cement, water, aggregate and plasticizer are given in *Table 1*.

Table 1. Experimental concrete mix (kg/m³)

Material		V%	kg/m³
aggregate	0/4 mm	40%	755
	4/8 mm	25%	472
	8/16 mm	35%	661
cement	CEM I 42.5 N		400
water	m_w/m_c=0.35		140
plasticizer cem. m%	1,50%		6

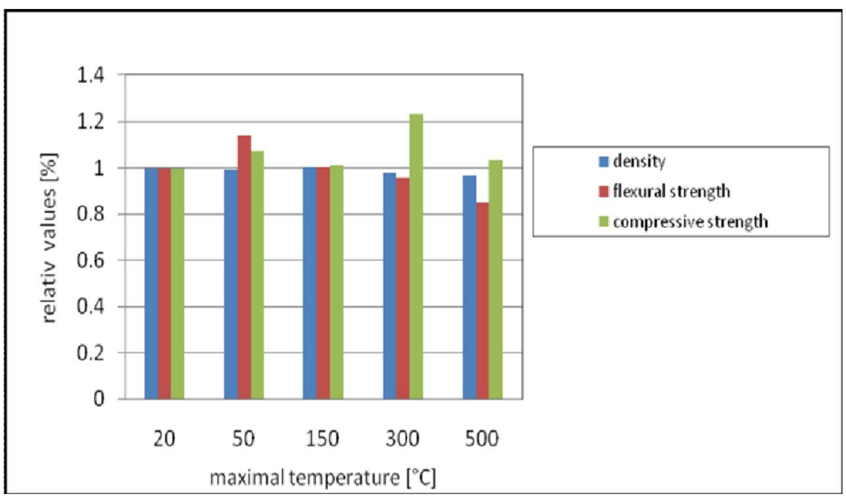

Figure 5. Density (based on CT measurments) as well as flexural and compressive strength measurements (based on mechanical test)

Development of residual compressive strength after fire is demonstrated in *Fig.5*. The following conclusions could be drawn:

- A strength valley is observed for relatively low values of maximal temperatures, i.e. a small strength decrease then small increase between 20°C to 300°C respectively. This valley might be explained by the pore water content of tested concretes at an age of 28 days. The valley ends up with about 100% strength.

- This valley is followed by decrease of compressive strength for higher values of maximal temperatures.
- Most considerable reduction of compressive strength took place between 300 °C and 500 °C.

4. X-RAY TESTING

As a new, non-destructive analysis method, the Computer Tomography (CT) technique originally was used for medical analysis. During the time of data processing the quality of the picture depends on many factors.
The displayed image is calculated from electrical signals by the imager, so it is not a real picture like a traditional photograph or a radiogram. The theoretical foundation of the CT measuring technique was made by Hounsfield and Cormack in the ‘70s [11].
X-ray is weakening as it goes through different materials and textures. The degree of absorption is smaller or higher in materials of different densities, therefore, it depends on the attributes of the measured materials.
The capability of X-ray absorption can be characterized by the coefficient of X-ray absorption. If the transfer of energy is constant, the absorption of X-ray depends only on the material through which it goes.
This degraded radiation reaching the detectors generates electrical signals dependent on the intensity of radiation.
As the system of tube detector turns around the analysed object, during the time of data collection hundreds or thousands of measurements are made by the CT while the incoming data is organized into a matrix. At the end of the process the imager calculates each element of the matrix and assigns a scale to the points of the matrix whose points are actually the coefficients of X-ray absorption.
This scale is the so called Hounsfield scale, its unit is the Houndsfield unit. (Nobel Prize was awarded jointly to Alan M. Cormack and Sir Godfrey N. Hounsfield for the development of computer assisted tomography in 1979.) Assigning the different values of the matrix to the appropriate values of the Hounsfield-scale the image can be displayed. We can visualize the image using predefined colour tables or our own colour ones [12].
The experiments were made with Simens Sensation CT with multislice technique. The resolution of a matrix depends on several factors. Using the best resolution of our CT the smallest size of a cell of a slice can be 0.1 mm x 0.1 mm x 0.8 mm in reality. The duration of time of the measurement can be set within the range of 0.1 to 1 second for one slice [13].
For the analysis of fire damage we applied a new test method: the computer tomography (CT) method. The method is applicable because the density and porosity values in function of temperature are changed *(Fig.4).*
After temperature loading the specimens were tested with computer tomography. Computer Tomography (CT) seems to able to demonstrate porosity differences in concrete (*Figs.6 and 7*).

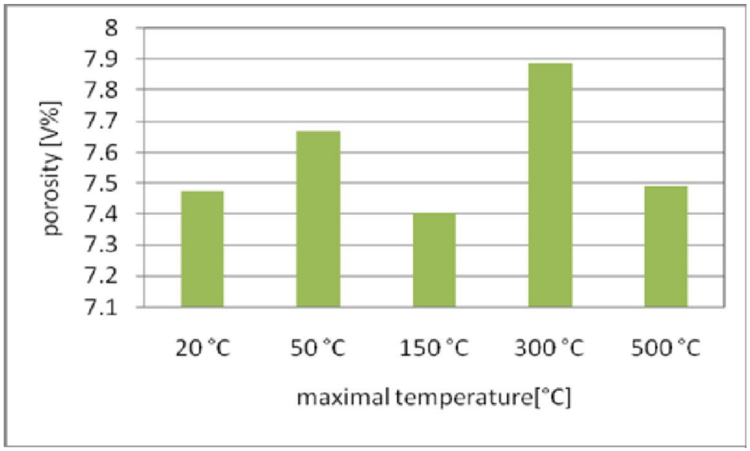

Figure 6. Porosity of specimens as a functions of temperature

In *Fig. 7* CT images shown for cross-sections of concrete specimens at room temperature (20 °C) as well as after 500 °C temperature loading. The CT image after 500 °C indicates higher numbers and higher diameter of pores at the specimens compared to room temperature.

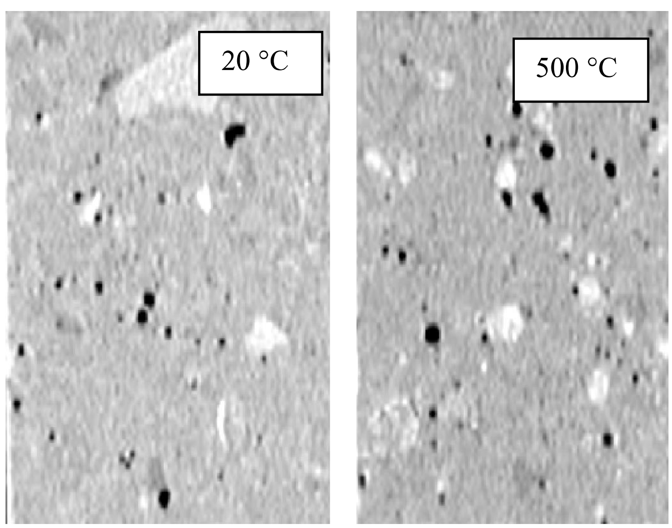

Figure 7. Pore distribution as a function of temperature (CT images)

5. CONCLUSION

In addition to the mechanical properties of structural materials, their behaviour during and after elevated temperatures are also of high importance. Residual compressive

strength of concrete exposed to high temperatures is influenced by the following factors water to cement ratio, cement to aggregate ratio, type of aggregate, water content of concrete before exposing it to high temperatures and the fire process.
High temperatures produce changes in material structure as well as changes in the mechanical properties. It is often a difficult question, how these changes can be detected and how pronounced are they. Our study concentrated on the extension of applicability of non-destructive testing methods. The potential in use of X-ray computer tomography (CT) was demonstrated with material testing.

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ЗАПАЖАЊА НА БЕТОНУ НАКОН ОПТЕРЕЋЕЊА ВИСОКИМ ТЕМПЕРАТУРАМА

Резиме: *Пожар може да изазове оштећења на бетонским конструкцијама. Ниво оштећења зависи од неколико фактора као пто су највиша температура, трајање пожара, састав бетона итд. Наша је обавеза да пројектујемо објекте да буду отпорни на дејство пожара и да решавамо проблеме могућих реконструкција након пожара. У оба случаја потребна су специјална знања и специјална дијагностика стања. За потребе реконструкције веома је важно да се утврди степен оштећења и неопходне интервенције након пожара. Уколико је могуће да се објекат реконструише недеструктивне методе утврђивања стања су од велике важности у анализи стварних оштећења. За потребе анализе оштећења од пожара у нашој лабораторији смо применили нови метод тестирања: компјутерска томографија (CT). Овај метод је примењив зато што су густина и порозност промењиви у функцији температуре.*

Кључне речи: *Високе температуре, бетон, X-зраци, компјутерска томографија*