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Non-Linear Characteristics of Temperature Degraded Concrete at High Temperature

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Abstract

Concrete structures are also commonly exposed to thermal loads as the result of the structure, ambient conditions, the heat of hydration, or exposure to fire. Therefore, there has been a growing interest in research on the advanced monitoring and analysis of concrete structures subjected to thermal load. The non-linear characteristics have been used to identify thermal damage evolution in concrete structures. This paper presents the effects of a high temperature on selected physical properties of concrete. Concrete properties were monitored and analyzed loaded in a few thermal steps up to 1200 °C. Therefore, the concrete specimens were heated in a programmable laboratory furnace at a heating rate of 5 °C/min. The specimens were loaded at six temperatures, i.e., 200 °C, 400 °C, 600 °C, 800 °C, 1000 °C and 1200 °C maintained for 60 minutes.

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1. Introduction

Fire can cause damage in a concrete structure with the damage level depending on several factors, mainly maximal temperature and duration. However, a common problem of different types of concrete structures is their properties in some very specific application areas. A typical example of a concrete property is its fire resistance. Temperature plays an important role in the use of concrete for different civil engineering structures not only nuclear power reactors,

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furnaces, cooling towers, but due to the terrorist attacks also bridges, high-rise buildings and others. The temperature changes of concrete cause both physical and chemical changes to take place in the cement matrix as well as in the aggregates. Therefore, the analysis is complicated due to the fact that cement concrete is a composite consisting of two substantially different constituents [1]

Table 1 lists the expected changes of concrete components, cement paste and aggregates according to the temperature of their occurrence.

Table 1. The changes of thermally degraded concrete [2].

Temperature [°C]	Changes
20 – 200	slow capillary water loss and reduction in cohesive forces as water expands
80 – 150	ettringite dehydration and C-S-H gel dehydration
150 – 170	gypsum decomposition ($CaSO_4 \cdot 2H_2O$) and physically bound water loss
~ 350	break up of some siliceous aggregates (flint) and critical temperature of water
460 – 540	portlandite decomposition, thus $Ca(OH)_2 \rightarrow CaO + H_2O$
~ 570	quartz phase change $\beta - \alpha$ in aggregates and sands
600 – 800	second phase of the C-S-H decomposition, formation of β-C_2S
~ 840	dolomite decomposition
930 – 960	calcite decomposition $CaCO_3 \rightarrow CaO+CO_2$, carbon dioxide release and ceramic binding initiation which replaces hydraulic bonds
1050	basalt melting
> 1200	total decomposition of concrete, melting

Ultrasound techniques are powerful tools in non-destructive testing and materials evaluation [3]. The impact acoustic emission is the term for the noise emitted by material and structures when subjected to stress caused by very intensive and short impulse(s). The waves, generated by the impulse, travel from the source to the sensors where they are converted to electrical signals [4].

2. Material and experimental setup

The experiments have prepared concrete samples with dimensions of 0.1 m x 0.1 m x 0.4 m. Specimens were made according to the following mixture consisting of Portland cement CEM I 42.5 R of 345 kg/m^3, sand 0/4 of 848 kg/m^3, gravel aggregate 8/16 of 980 kg/m^3, superplasticizer of 2.8 kg/m^3, and water of 160 kg/m^3 in a laboratory of the Institute of Technology of Building Materials and Components at Brno University of Technology, Faculty of Civil Engineering.

For 28 days, the specimens were soaked in water with a temperature of 20 °C and then dried at first at the laboratory temperature of 20 °C and then 48 hours in a furnace at a temperature of 110 °C. The concrete specimens were heated in a programmable laboratory furnace at a heating rate of 5 °C/min and heated at a selected temperature for 60 minutes and then spontaneously cooled down to 20 °C. The selected temperatures were 200 °C, 400 °C, 600 °C, 800 °C, 1000 °C and 1200 °C.

The ultrasound impulse tests were performed after thermal degradation. Twelve specimens from each temperature were tested. The experimental set up is in Fig. 1. An impulse exciter was located at the centre of the cross section on the left-hand side as shown in Fig. 1. Four ultrasound sensors were attached to the surface by beeswax. One sensor was placed near the exciter, a second one on the opposite side of the exciter, a third on the perpendicular side of sample, and a forth one on the same side as the first one, but on the right-hand side as shown in Fig. 1. Sensors three and four were located at 0.05 m from the opposite side of the exciter, that is, from the second sensor. Every specimen was excited by three different pulses, with amplitudes of 250 V, 500 V, and 1200 V, respectively. The Fourier spectra