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Concrete cone failure of bonded anchors in thermally damaged concrete

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HIGHLIGHTS

- In our paper we analysed the load bearing capacity of bonded anchors installed in thermally damaged concrete.
- Our primary goal was to facilitate the reinforcing techniques of reinforced concrete structural elements damaged in fire events.
- In our experiments, we tested the load bearing capacity of bonded anchors in thermally damaged concrete as a function of thermal load.
- By our research we also aimed to follow our results by development of a calculation method that helps the work of engineers during design of anchors.

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ABSTRACT

In our paper we analysed the load bearing capacity of bonded anchors installed in thermally damaged concrete. Our primary goal was to facilitate the reinforcing techniques of reinforced concrete structural elements damaged in fire events. In our experiments, we tested the load bearing capacity of bonded anchors in thermally damaged concrete as a function of thermal load (200, 300, 400 °C). By our research we also aimed to follow our results by development of a calculation method that helps the work of engineers during design of anchors installed in thermally damaged concretes.

1. Introduction

1.1. Concrete at elevated temperature

Hardened concrete is a composite material that consists mainly of two components: aggregate and cement stone. During increase of temperature both undergo some physical and chemical changes.

At higher temperatures strength properties deteriorate. Properties of concrete cannot be gained back after cooling down, because high temperatures cause irreversible changes in the structure of concrete that can cause deterioration and finally failure.

Failure of concrete at high temperatures (fire loads) has two main origins [1,2]: chemical changes in the components of concrete, spalling of concrete cover.

Strength of concrete at high temperatures mainly depends on the following [3]: type of cement, type of aggregate, water-cement ratio, aggregate-cement ratio, initial moisture content, way of temperature loading.

In the following we shortly summarize the most important physical and chemical changes in concrete subjected to high temperatures.

Around 100 °C decrease of mass is caused by evaporation of water from the macro pores. Decomposition of ettringite ($3CaOAl_2O_3{\cdot}3CaSO_4{\cdot}32H_2O$) takes place between a 50 °C and 110 °C [4,5]. Around 200 °C further dehydration occurs that causes decrease of mass. Water content (water-cement ratio), type of cement and age of concrete affect the amount of evaporated pore water and chemically bonded water. Initial moisture content can have significant effect on the loss of mass especially in case of light-weight concretes. Above 250–300 °C further decrease of mass cannot be detected.

Between 450 °C and 550 °C decomposition of not carbonated portlandite occurs ($Ca(OH)_2 \rightarrow CaO + H_2O\uparrow$). This process leads to an endothermic peak and consequently to further loss of mass [6]. Dehydration of portlandite causes the most significant loss of strength in concrete [7].

In case of conventional concretes α to β quartz inversion takes place at 573 °C with a smaller endothermic peak. This quartz inversion causes 5.7% volume increase [8], that leads to significant deterioration of concrete. Above this temperature concrete has no significant load bearing capacity.

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At 700 °C CSH (calcium-silicate-hydrate) compound decompose with water output that courses further volume increase and loss of strength [9].

Due to the physical and chemical change in concrete strength properties also change.

Test results [10–13] show that compressive strength of concrete decrease slightly below 300 °C, but significantly above 300 °C (Fig. 1). This phenomenon is caused by aggregate interlock. At lower temperatures, loss of strength caused by dehydration of cement paste can be partly compensated by aggregate interlock caused by thermal expansion. At higher temperatures this compensation is not adequate and decrease of strength is proportional to the increase of temperature.

Recent experimental investigations [11,13,14] show that tensile strength of concrete linearly decreases with increasing temperature (Fig. 2). Tensile strength of concrete is more sensitive to temperature changes that is caused by micro cracks.

Modulus of elasticity of concrete also linearly decreases with increase of temperature [11,14,15] (Fig. 3). At lower temperatures it is caused by the loss of capillary water, while at higher temperatures degradation of cement paste and aggregates cause the decrease of modulus of elasticity.

Fracture energy of concrete increases up till 300 °C and with further increase of temperature it decreases (Fig. 4) [11,14]. The initial increase is also the consequence of aggregate interlock that increases ductility of concrete. Above 300 °C micro crack formation, dehydration and decomposition of the cement paste becomes dominant.

Residual strength of concrete is also affected by the type and rate of cooling down. According to *CEB* [16] residual strength after slow and fast cooling down can be distinguished. Other tests [17] examined further methods of cooling down (at laboratory conditions, by forced ventilation, in water fog, in water).

Other source of concrete failure in case of fire is spalling, that has two main reasons:

1) increased pore pressure causes spalling of the surface layer of concrete.
2) the exposed zone cannot bear further stresses caused by heat expansion therefore it cracks an crushes [18].

1.2. Anchorage in concrete

Several post-installed anchors are available with different methods of load-transfer. The commercially available fastenings can transfer the load to the host material via the following mechanisms: mechanical interlock, friction or bond. Furthermore, the most recent techniques use combined bond and friction (e.g. bonded expansion anchors). In case of expansion anchors, the load is transferred by friction. Generally, an expansion sleeve is expanded by an exact displacement or torque applied on the anchor head during the installation process. Chemical fastenings are anchored by bond. Bonded anchors can be divided into two subgroups: capsule or injection systems. The bond material can be either organic, inorganic or a mixture of them. In this case the loads are transferred from the steel (normally a threaded rod, rebar) into the bonding material and are anchored by bond between the bonding material and the sides of the drilled holes. The load bearing capacity of bonded anchors with the same embedment depth depends on the type of the resign [19–21].

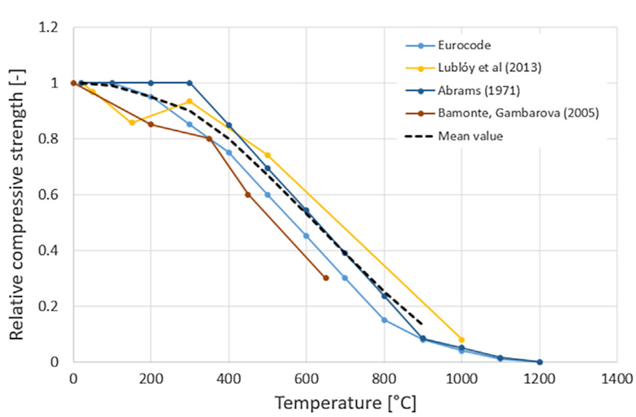

Fig. 1. The dependency of the relative concrete compressive strength on the temperature.

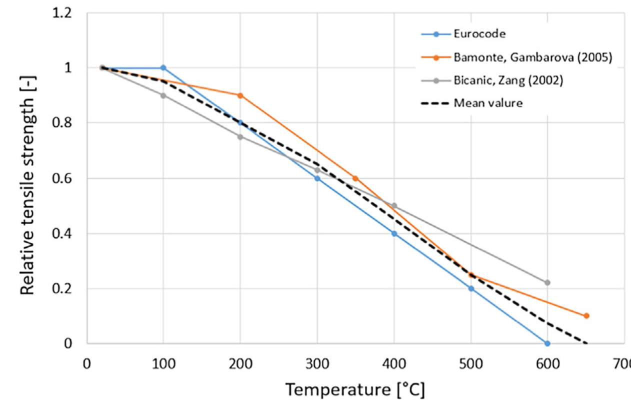

Fig. 2. The dependency of the relative concrete tensile strength on the temperature.

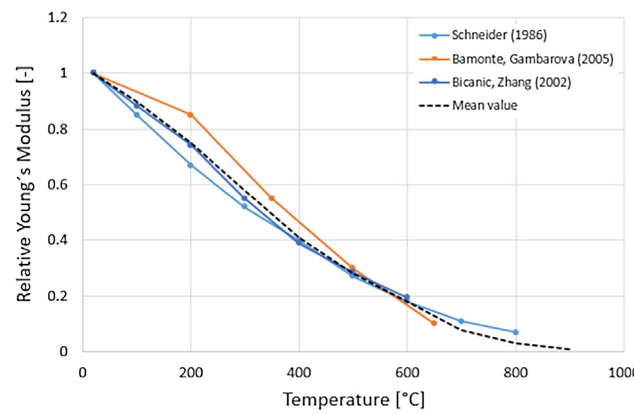

Fig. 3. The relative Young's modulus of concrete as function of temperature.

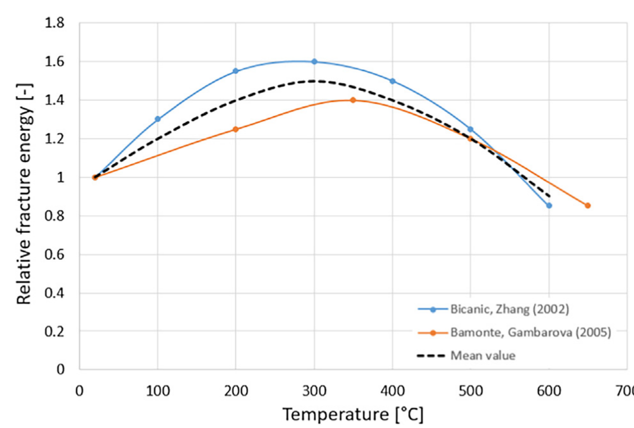

Fig. 4. The relative fracture energy of concrete as a function of temperature.