

## Concrete Permeability and Explosive Spalling in Fire

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**Abstract.** Permeability of concrete is a good indicator of the risk of explosive spalling, concrete with low permeability is more prone to explosive spalling. To study explosive spalling of concrete, experimental tests on the concrete permeability have been carried out at ETH. The influences from temperature and moisture content have been investigated. The permeability of concrete is found to increase with the temperature and to decrease with moisture content. Based on the test results, a permeability model has been proposed. The explosive spalling has been predicted and an engineering boundary permeability for the liability to spalling is recommended to be  $2 \times 10^{-17} \text{ m}^2$  for a concrete slab heated according to ISO fire curve. The boundary permeability is influenced by moisture content, tensile strength and heating rate.

### Introduction

Concrete is the most used building material in construction since many years due to its wide applicability and low cost. The fire resistance of concrete elements is usually good and the penetration of heat is slow, because concrete has a relatively high thermal capacity and low heat conductivity. With the development of modern technology and the increasing requirements for durability, concrete becomes denser, especially when silica fume is used to increase the concrete performance. High performance concretes (HPC) are more and more used in high-rise buildings or tunnels. Apart from the advantages of high density, high strength and good durability, the elements made of HPC have been reported more prone to fire spalling [1], leading to a reduced fire resistance. Therefore, explosive spalling of concrete induced by fire exposure has been a major concern in the use of HPC.

Since decades a lot of effort has been paid to study the nature of explosive spalling of concrete. Research has shown that the pore pressure is one of the most important parameters in explosive concrete spalling in fire [2] and the high pore pressure induced by the low permeability makes HPC more susceptible to explosive spalling. The permeability of concrete is a good indicator of the risk of explosive spalling. To predict the spalling of concrete, permeability measurements have been carried out at ETH Zurich. The test results indicate that the permeability of concrete is influenced by temperature, pore pressure and moisture content. A permeability model has been proposed to predict the permeability of concrete at high temperature. The risk of explosive spalling can be estimated considering the permeability.

Details of the permeability measurements and the permeability model will be presented in this paper. The boundary permeability of liability to spalling has been proposed using the permeability model.

### Permeability measurements

The permeability of concrete varies with temperature and pore pressure. In addition, Jacobs [3] and Harmathy [4] indicated that the permeability is significantly influenced by moisture content. To interpret the influences from these factors, concrete specimens with different moisture contents have been investigated. Two methods, namely residual- and hot permeability have been compared and test results have shown that the two methods were in good agreement [13]. Therefore, the easily applicable residual permeability measurement will be chosen to investigate the effects from temperature, pore pressure and moisture content. The residual permeability is measured by the

