CrossFire
Advanced Structural Fire Engineering at Intersections Among Disciplines
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A new perspective on concrete spalling in fire

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Spalling definition and requirements

From a structural standpoint, spalling becomes significant when it leads to a loss in cross-sectional area and rebar protection

This involves both fracturing of the cover and detachment of splinters, and then the fulfillment of two conditions:

A. initiation of an incipient fracture

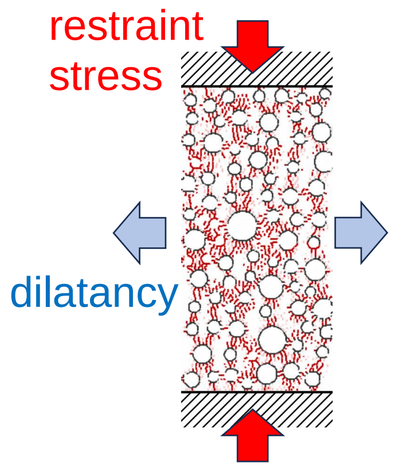
B. unstable crack propagation and fast splinter separation

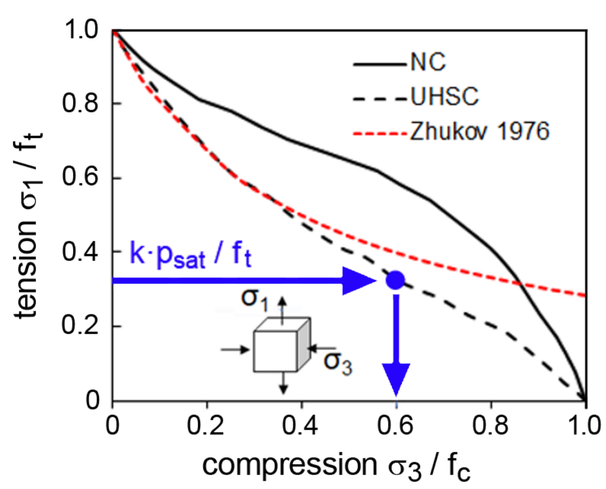
stable delamination (no spalling)

fast propagation and splinter detachment

A. initiation of an incipient crack

- high compressive stress due to restrained thermal dilation (fostered by pore pressure)
- meso-scale heterogeneity (flaws parallel to the compressive stress develop at Interfacial Transition Zone)
- convex shape of the element (corner spalling, lab specimens)
- weak planes and strain incompatibility entailed by the reinforcement





experimental evidence

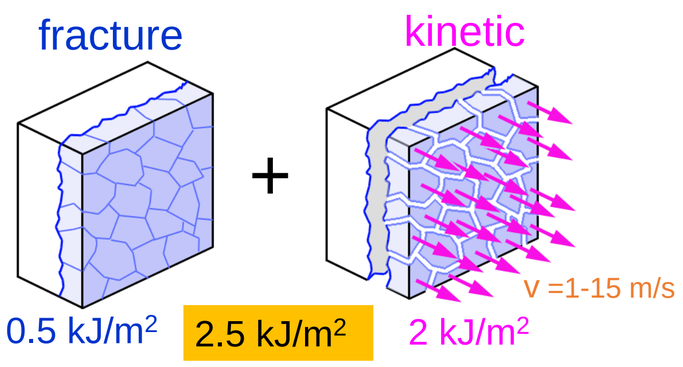
- effective stress due to pore pressure can prevail on tensile strength just beyond 300°C (UHPC)
- restraint stress tests show moderate stress peaks but significant transverse dilatancy

B. unstable crack propagation

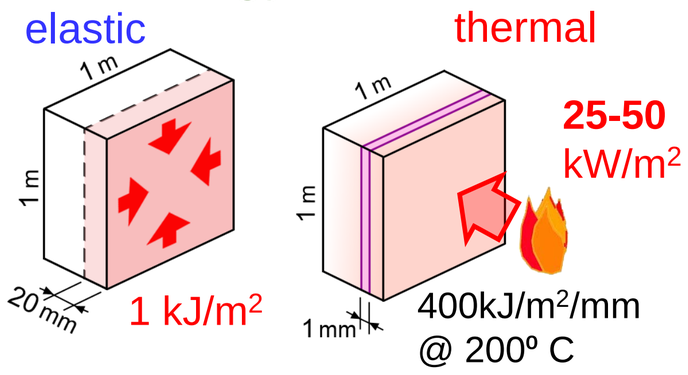
what drives this phenomenon?

- thermal energy is larger than elastic strain energy by several orders of magnitude
- thermal energy is converted into mechanical work by way of water vaporization (1% drying = -16°C)
- fast flow of vapour into the opening crack requires a very short filtration path (time ≈ distance²)

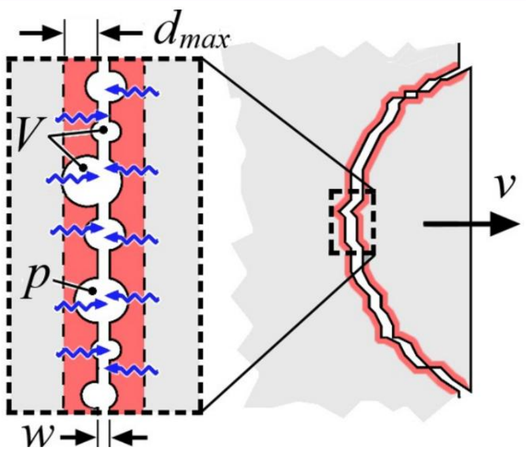
energy required



energy available



the concept of the **influencing region**: a fairly saturated submillimetre layer facing the two faces of the opening crack

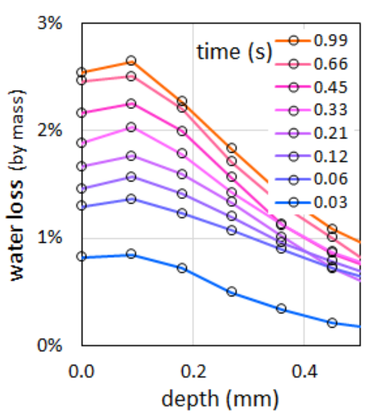


*vaporizing and expanding **3%** of water in a **0.1 mm** layer facing both faces of the crack develops **4 kJ/m²***

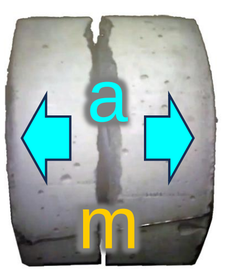
saturation has a pivotal role !!

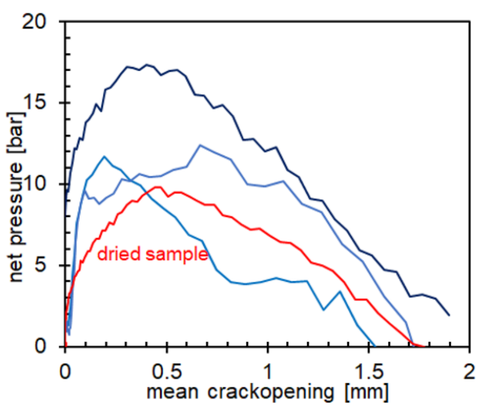
- concrete permeability and age
- environmental service conditions
- polypropylene fibre

experimental evidence



flash vaporization revealed by Neutron Radiography





net pressure in the opening crack inferred from mass acceleration

this two-stage scheme clarifies the role of all governing factors

stage	mechanism	governing factors
crack initiation	thermal stress	heating rate, thermal dilation, material stiffness, element thickness, boundary conditions, applied load
	meso-scale heterogeneity	mix design, coarse aggregate
	pore pressure	heating rate, permeability, pore saturation
	tensile stress at corners and edges	element geometry
	stress concentration due to rebars	reinforcement geometry and material
crack instability	elastic energy	same as thermal stress
	thermal energy	heating rate, pore saturation
	inherent material brittleness	concrete grade, coarse aggregate

references

Fast vapour migration next to a depressurizing interface: A possible driving mechanism of explosive spalling revealed by neutron imaging
Cement and Concrete Res., 2024

Crack instability of concrete in fire: A new small-scale screening test for spalling
Cem. and Concr. Composites, 2024

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