



Influence of curing temperature on
development of compressive strength and
resistance to chloride ingress of concrete with
different binder systems

Martin Kaasgaard, Claus Pade, Erik Pram Nielsen
Danish Technological Institute

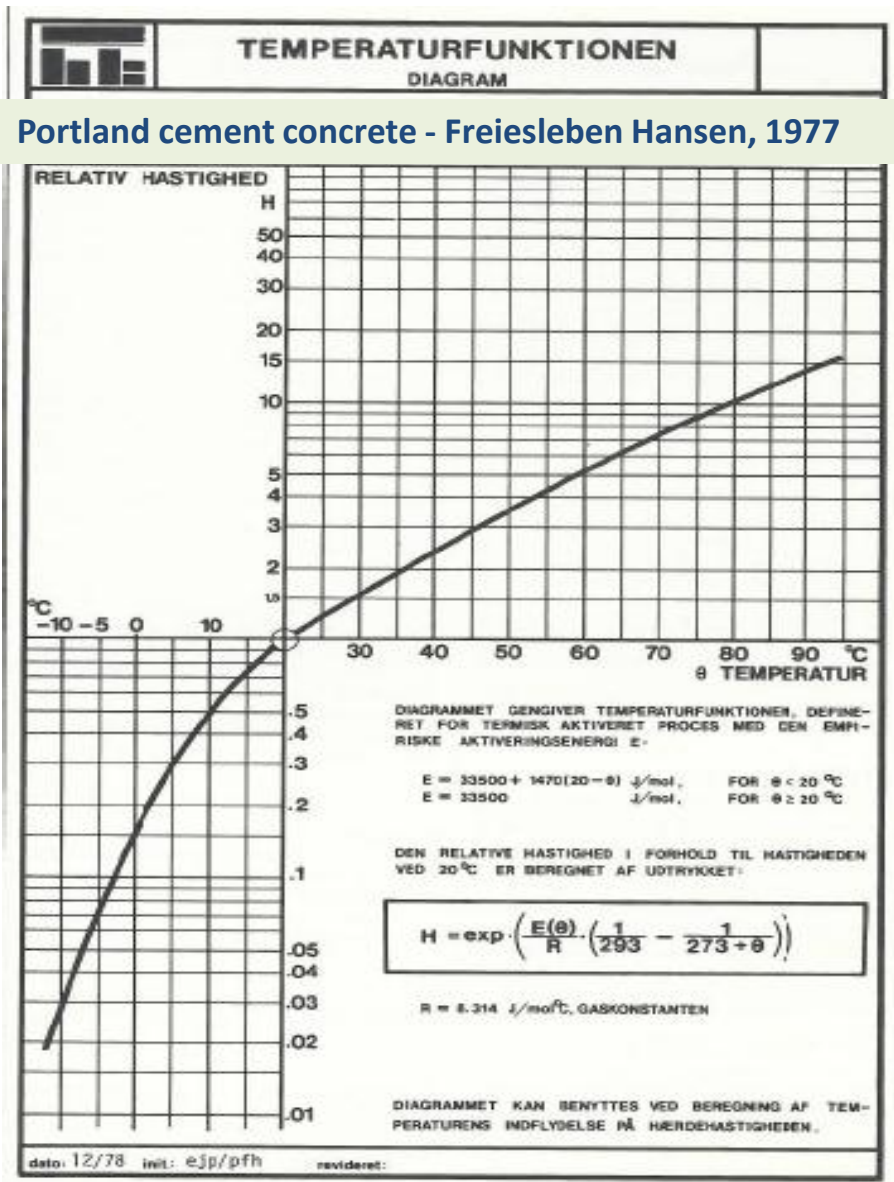
Scope 1

- In Denmark, the maturity concept is used for estimating the strength development of a concrete as a function of temperature – based on data measured at 20 degrees

Input to:

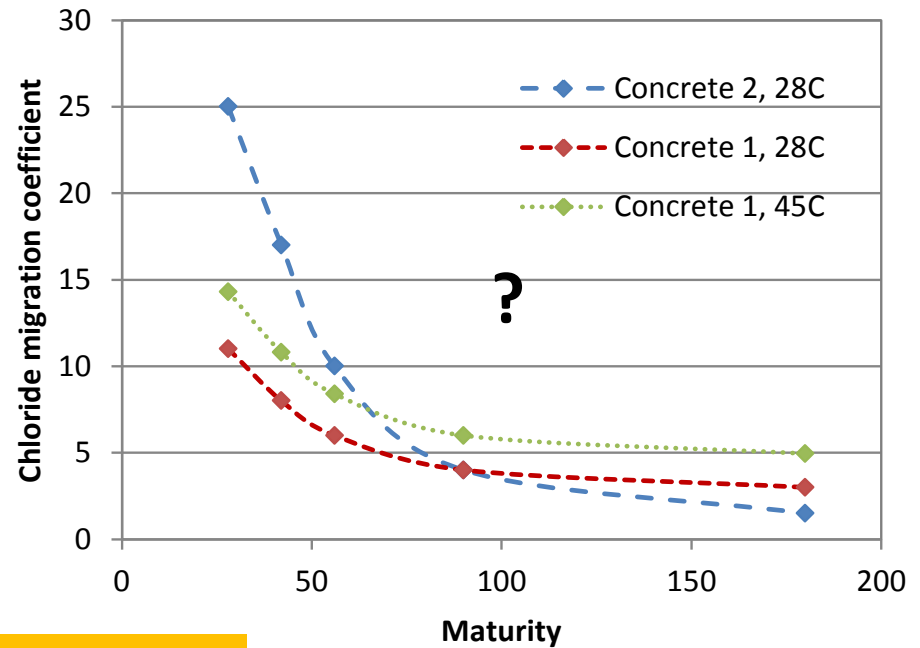
- Optimization of curing
- Striping of formwork
- Evaporation protection
- Selection of binder combination
- Early age crack control

Portland cement concrete - Freiesleben Hansen, 1977



Scope 2

Is it possible to use a similar relation to describe the development of resistance to chloride ingress??



Input to:

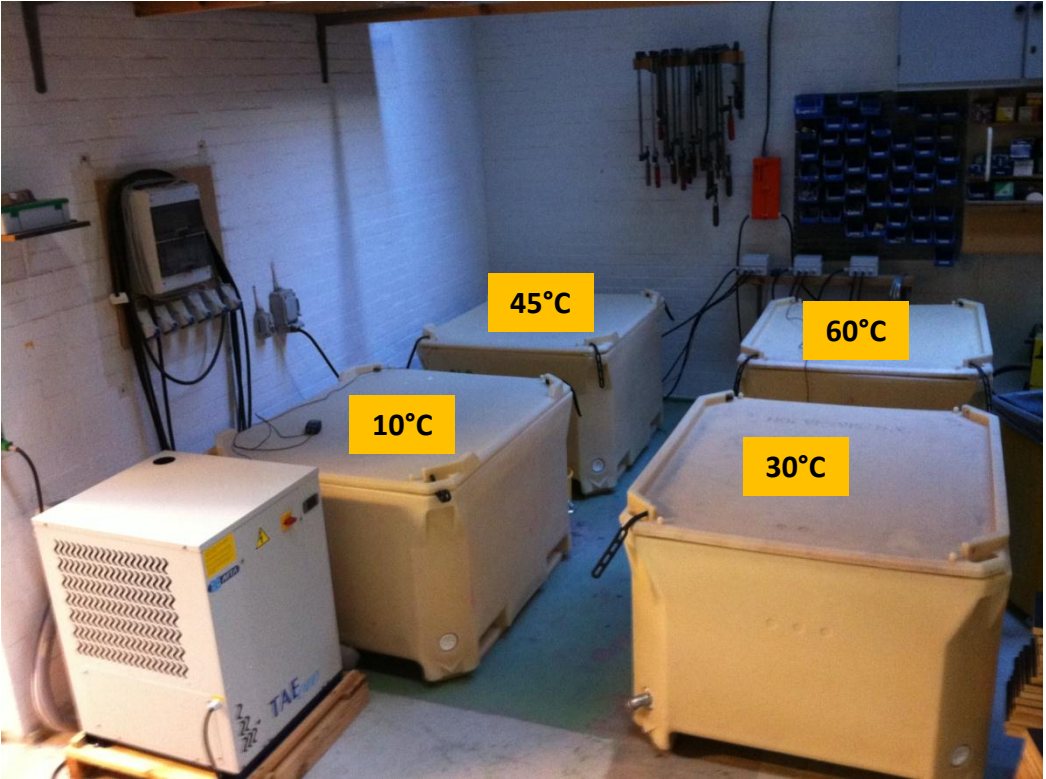
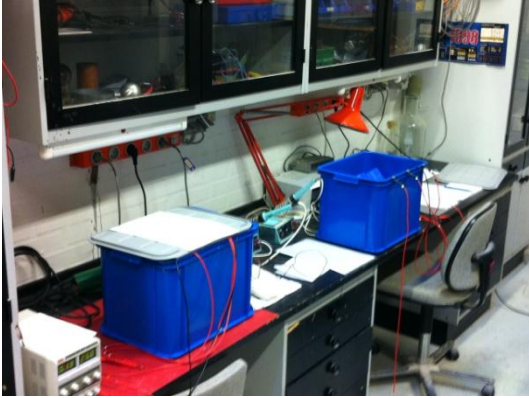
- selection of binder combination
- optimization of curing
- choice of maturity at first exposure

Experimental program

	10°C	20°C	30°C	45°C	60°C	
RPC	MPa: 1,2,7,28, 56 days	MPa: 1,2,7,28, 56,180 Days	MPa: 1,2,7,28, 56 Days	MPa: 1,2,7,28, 56 days	MPa: 1,2,7,28, 56 Days	Slump 120-180 mm ΔAir content < 0,5% between batches EN 480- 11/batch NTB388/ batch
SRPC	NTB492: 28,56,90 ,180 days	NTB492: 28,56,90 ,180 days	NTB492: 28,56,90 ,180 days	NTB492: 28,56,90 ,180 days	NTB492: 28,56,90 ,180 days	
RPC + 25% fly ash	NTB443: 28, 180 days	NTB443: 28, 180 days	NTB443: 28, 180 days	NTB443: 28, 180 days	NTB443: 28, 180 days	
SRPC + 25% fly ash						
CEM III/B						
SRPC + 4% SF						
SRPC + 4% SF + 12% FA						

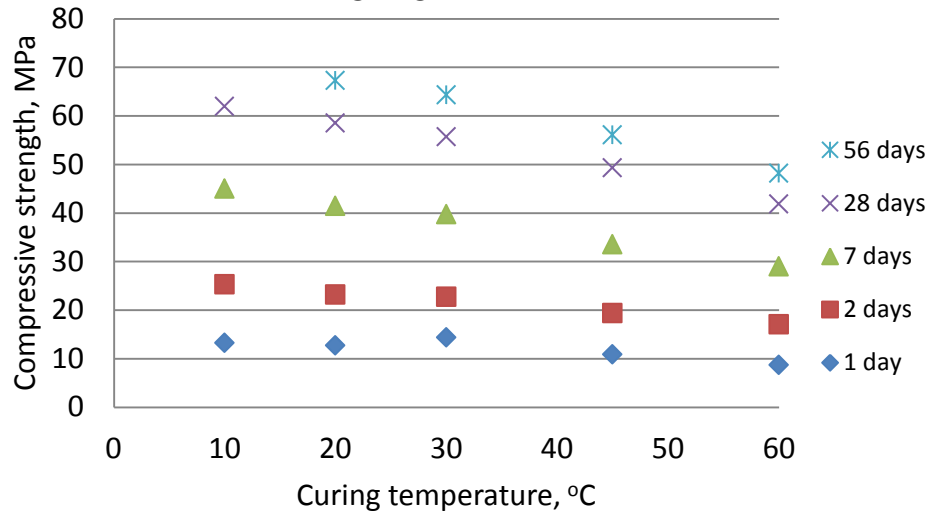
Each concrete type: eq. w/c-ratio at 0.40, dmax = 22 mm

78 Ø150 cylinders
30 Ø100 cylinders } 500 liter

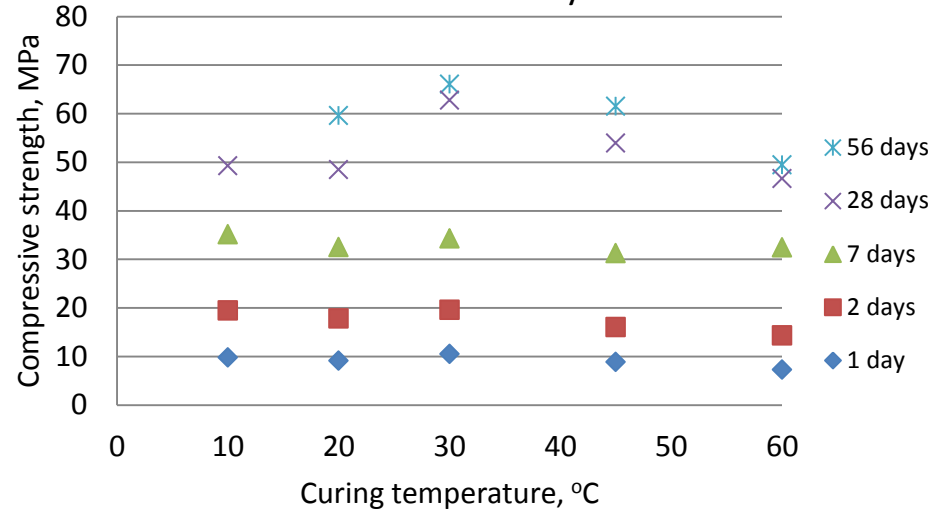


Strength development (in Maturity-days)

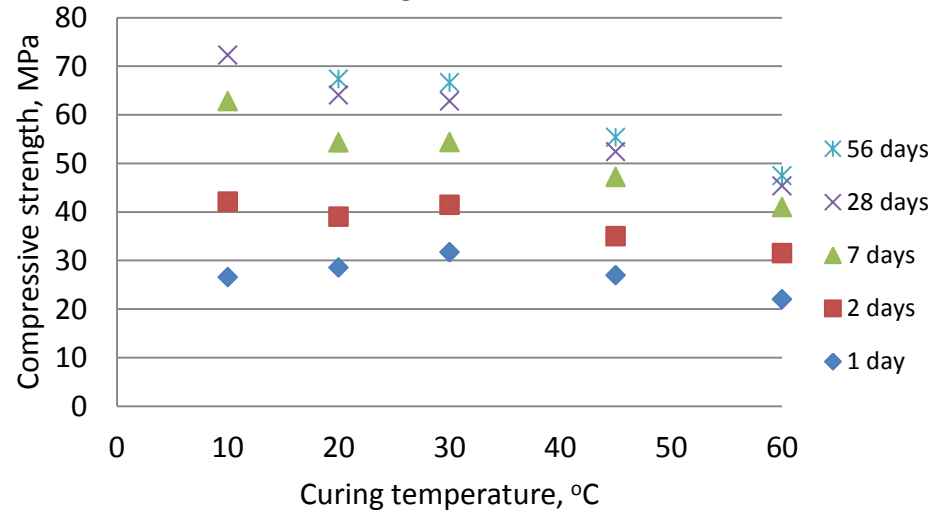
SRPC



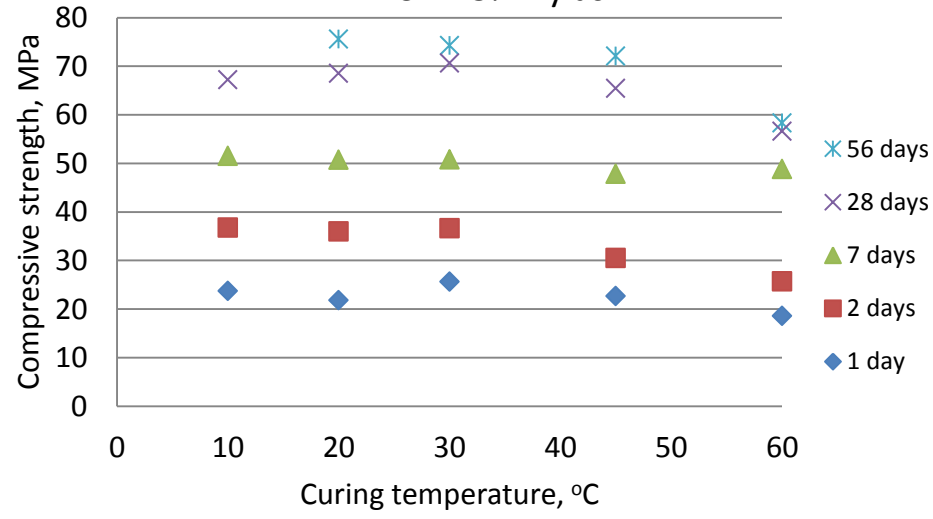
SRPC + 25% fly ash

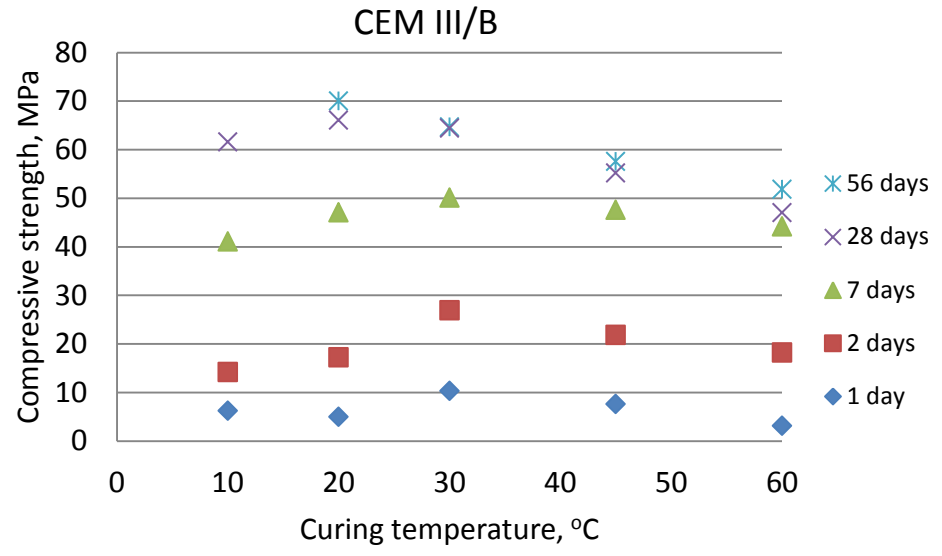


RPC



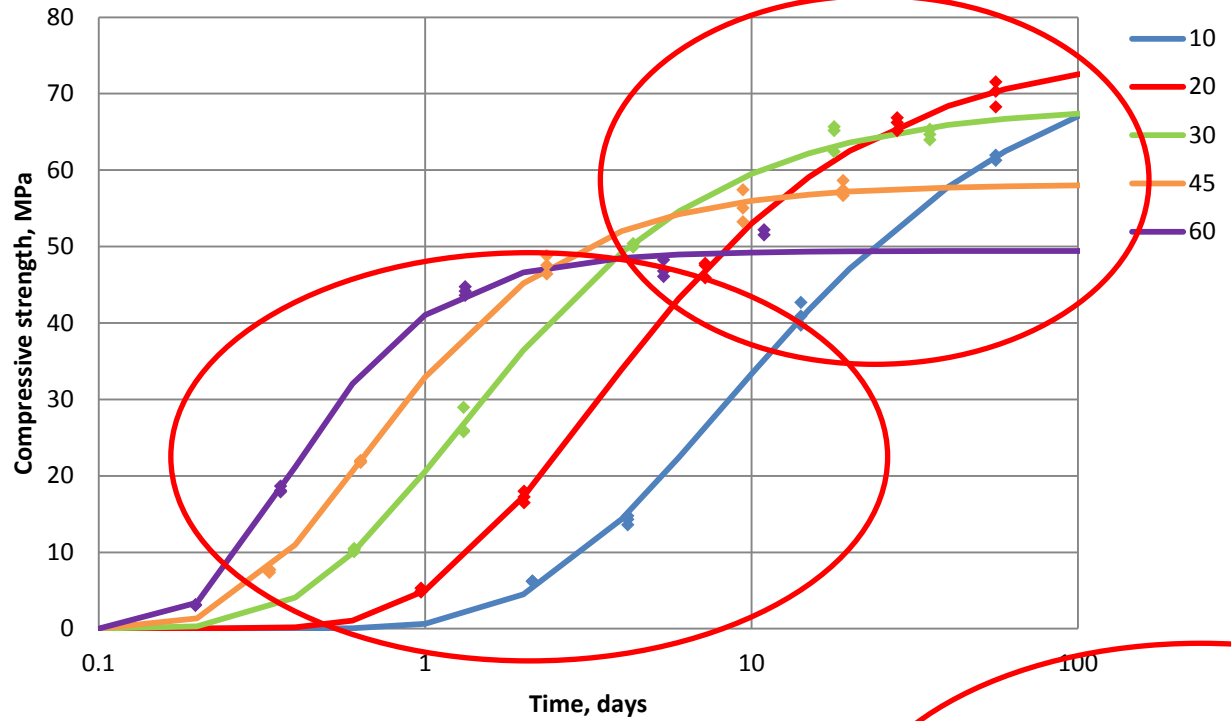
RPC + 25% fly ash





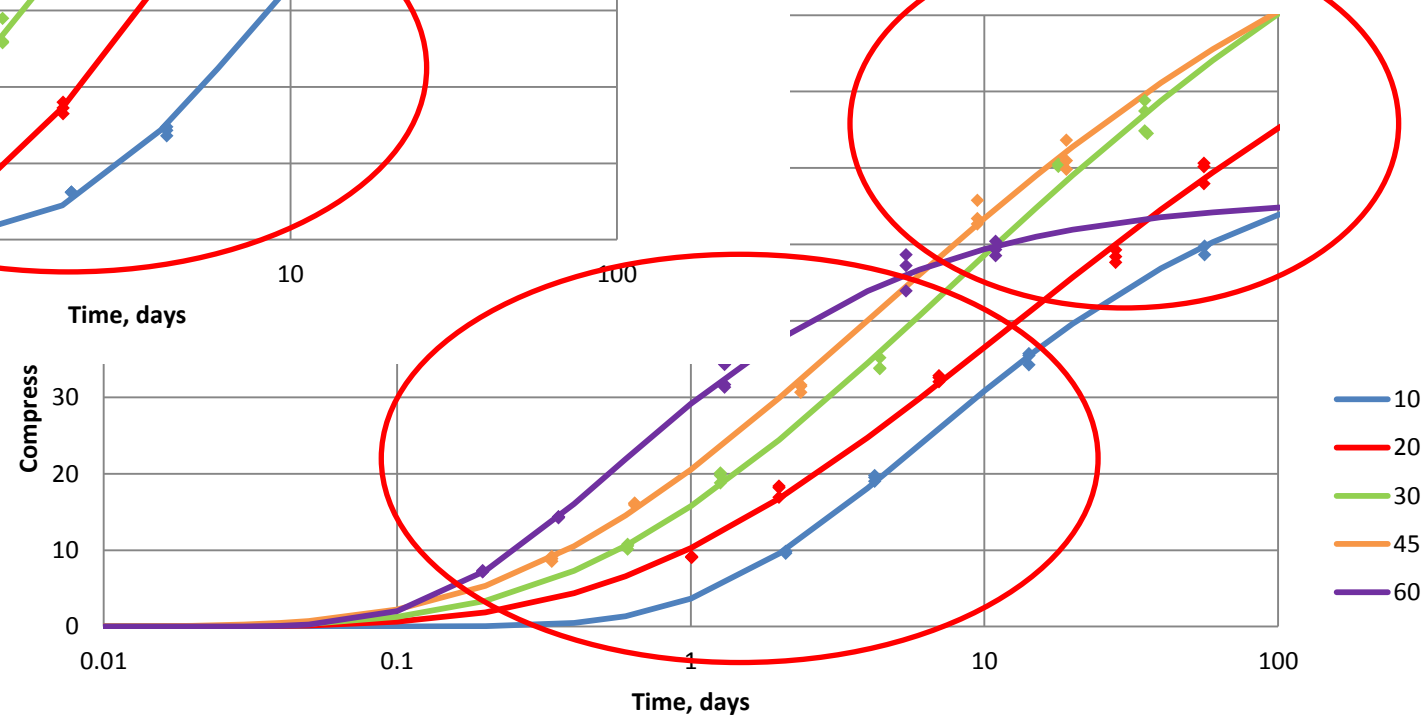
Strength development

CEM III/B



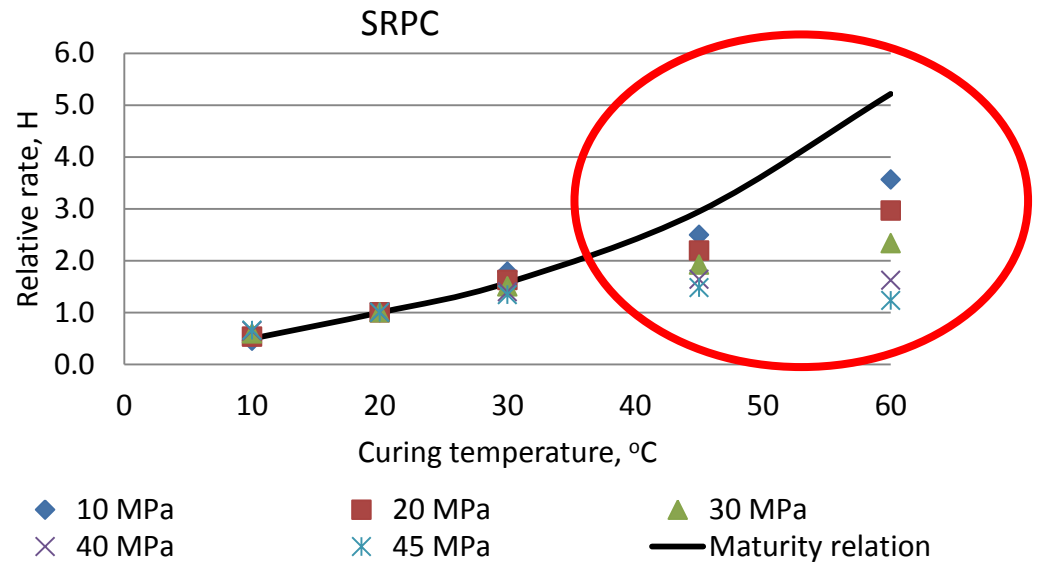
Ultimate strength significantly affected by curing temperature?

SRPC + 25% fly ash



Rate is examined up to 45 MPa for practical purposes

Relative rate of strength development

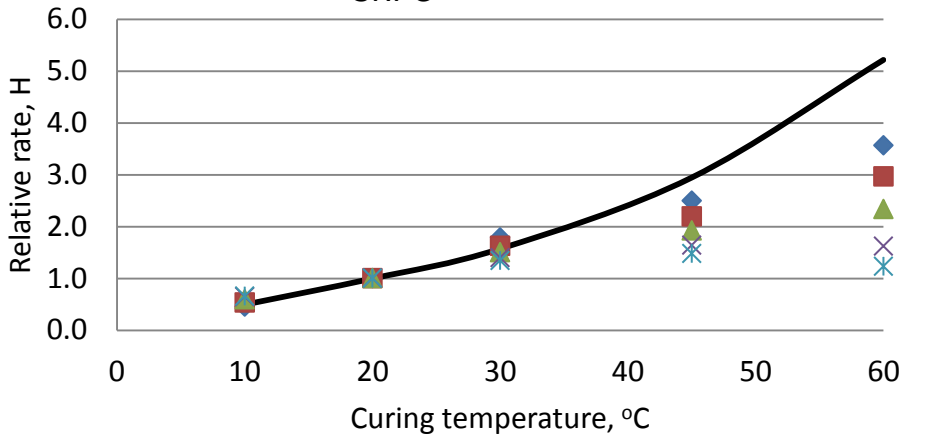


At high temperatures, the rate of strength development is dependent on the degree of hydration!

The energy of activation may be a function of temperature!

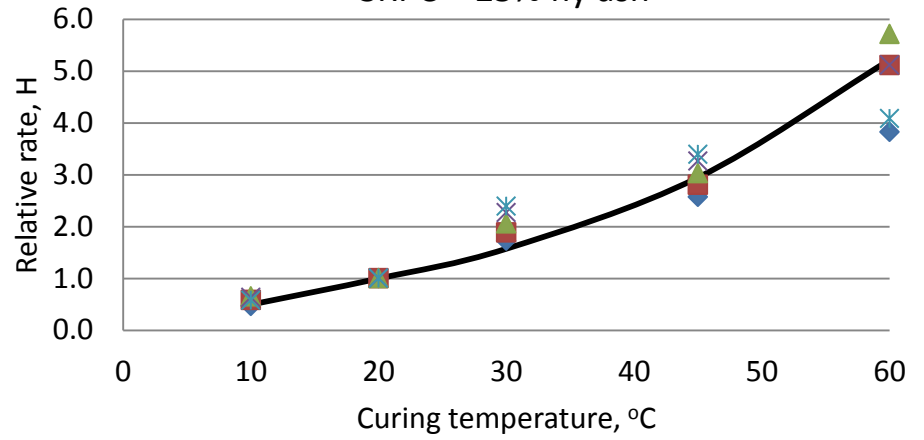
Relative rate of strength development

SRPC



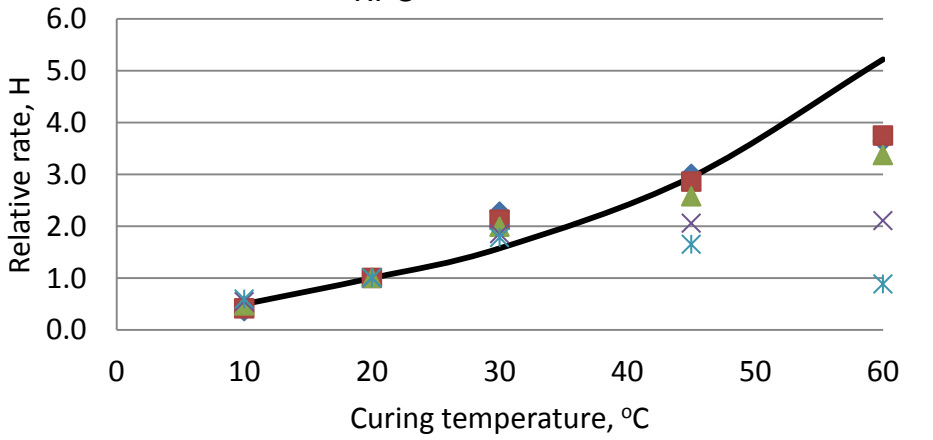
- ◆ 10 MPa
- ◆ 20 MPa
- ◆ 30 MPa
- × 40 MPa
- × 45 MPa
- Maturity relation

SRPC + 25% fly ash



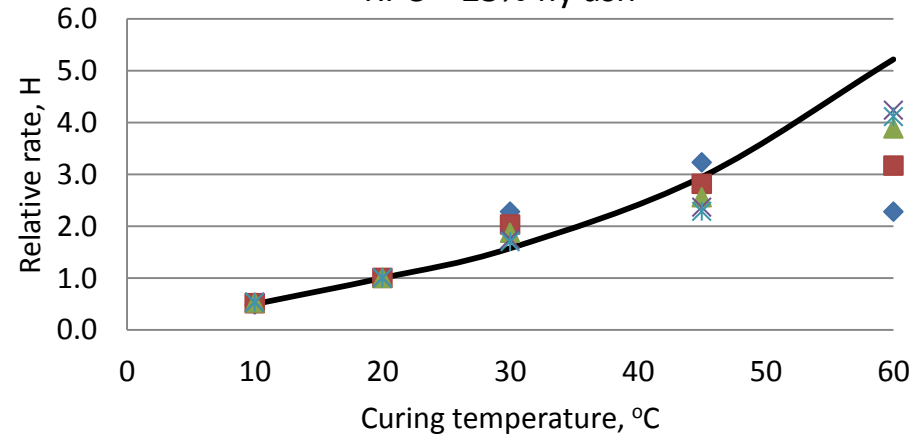
- ◆ 10 MPa
- ◆ 20 MPa
- ◆ 30 MPa
- × 40 MPa
- × 45 MPa
- Maturity relation

RPC



- ◆ 10 MPa
- ◆ 20 MPa
- ◆ 30 MPa
- × 40 MPa
- × 45 MPa
- Maturity relation

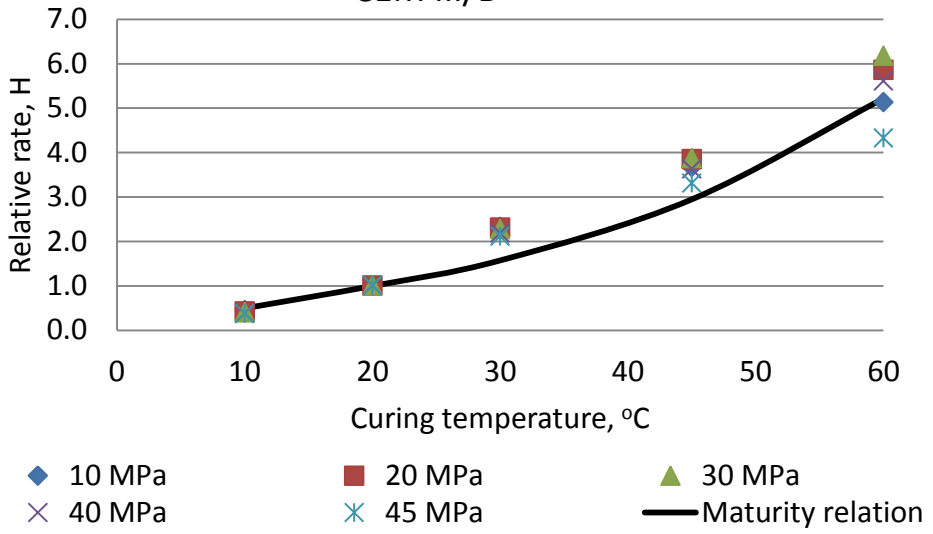
RPC + 25% fly ash



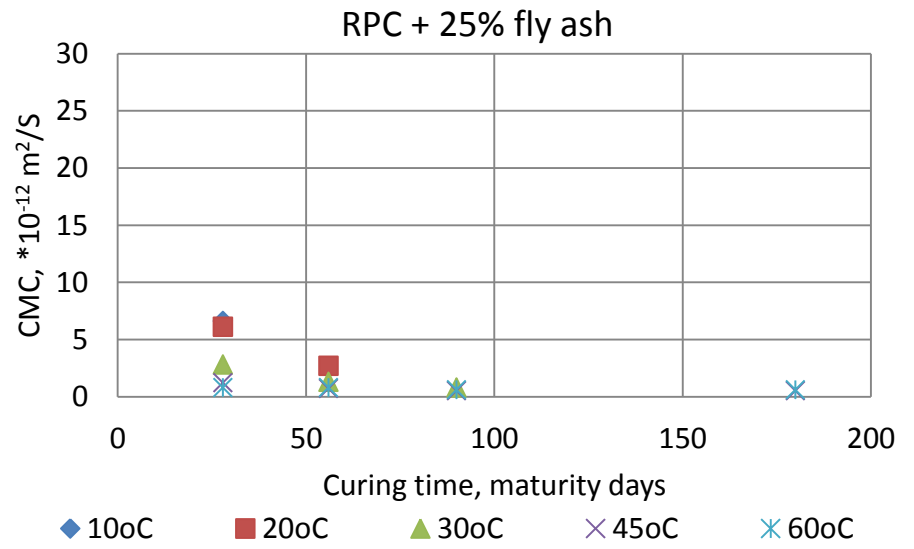
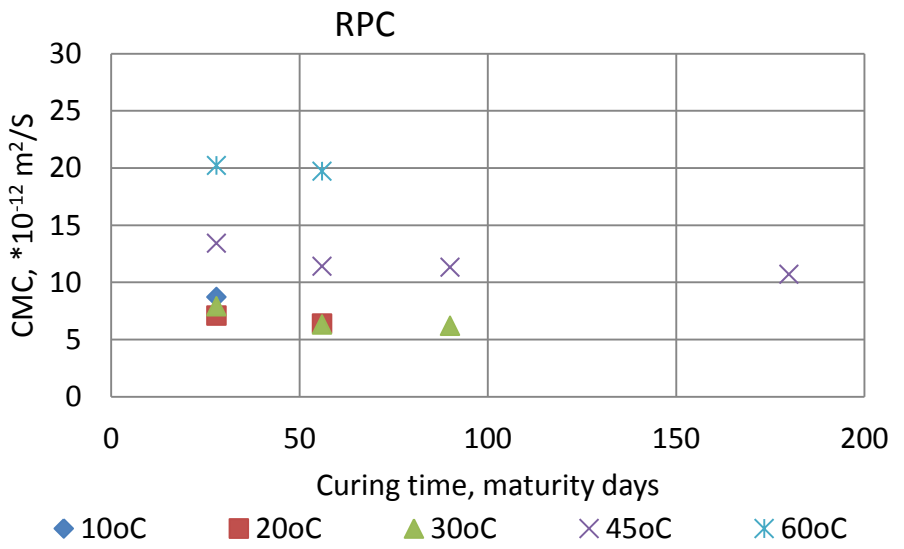
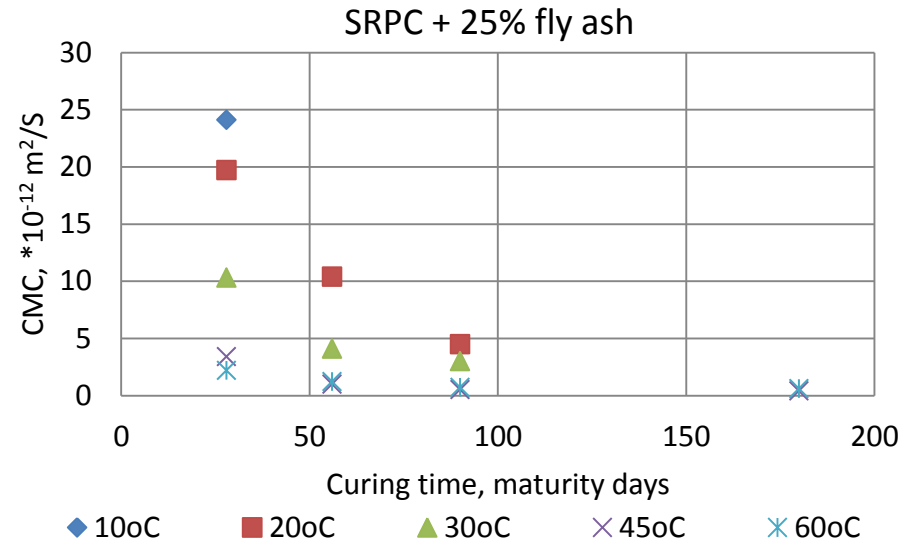
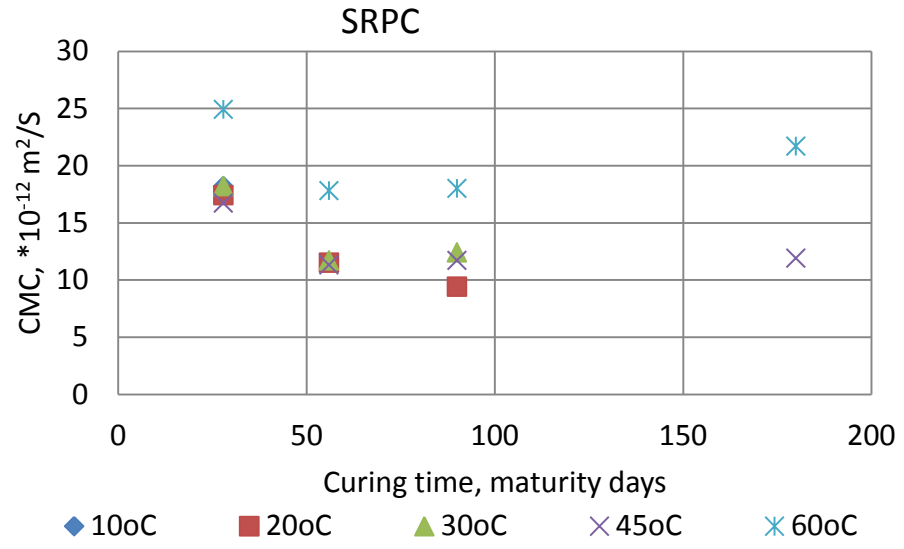
- ◆ 10 MPa
- ◆ 20 MPa
- ◆ 30 MPa
- × 40 MPa
- × 45 MPa
- Maturity relation

Relative rate of strength development

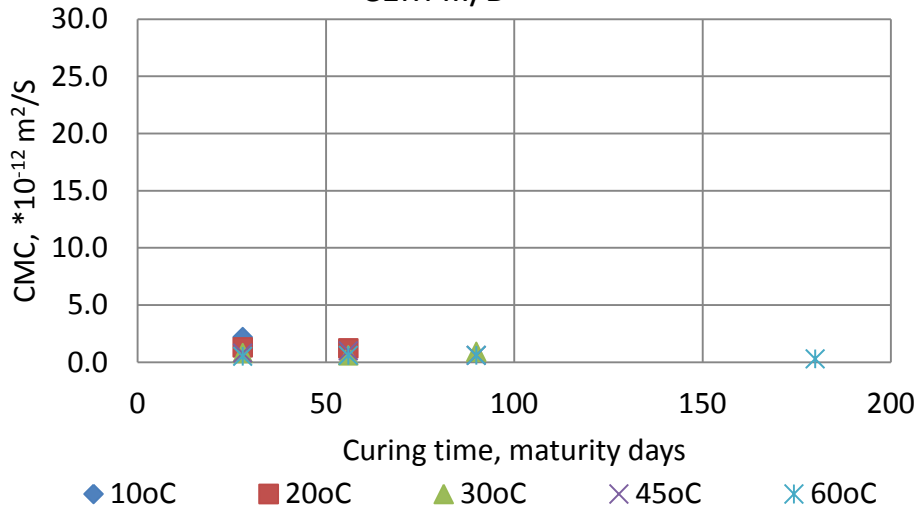
CEM III/B



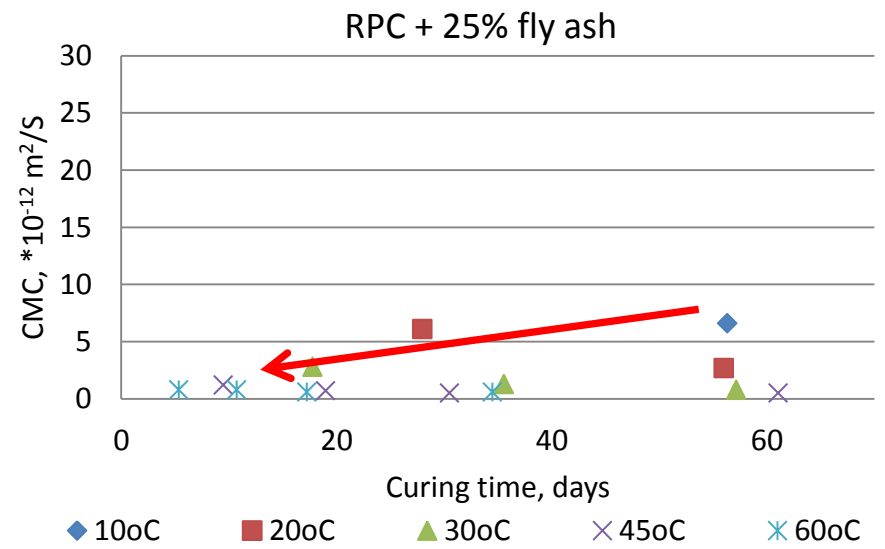
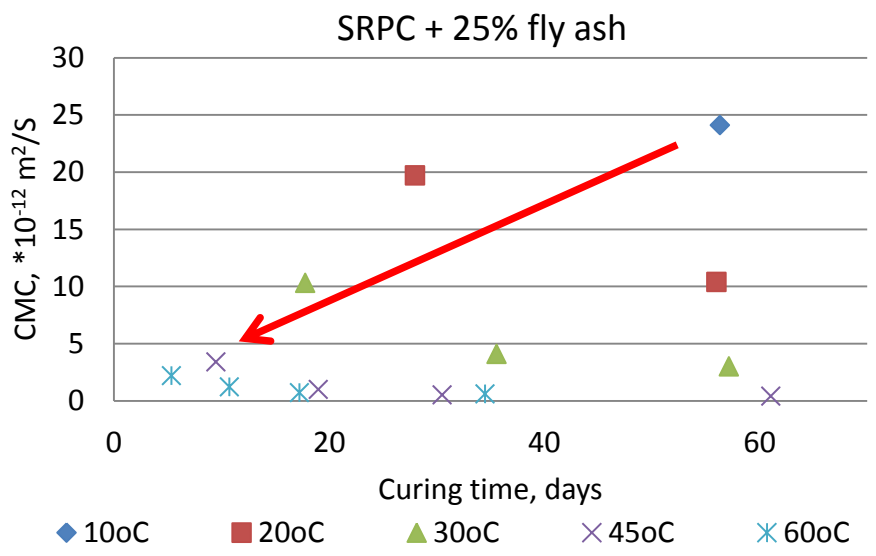
Resistance to chloride ingress (CTH vs. maturity days)



CEM III/B



■ Practical implications – curing strategy



- The maturity relation by Freiesleben provides an accurate description of the rate of strength development for curing temperatures up to ~ 30 °C
- The accuracy of this relation drops significantly for curing temperatures above 30°C, where the rate becomes highly affected by the degree of hydration
- The ultimate strength of a concrete is remarkably affected at curing temperatures around 60 °C
- Performance of fly ash concretes is greatly improved by high-temperature initial curing
- Slag cement concretes show very good resistance to chloride ingress at short curing times and at all studied curing temperatures
- All studied concretes show remarkably different behaviour with respect to both strength development and resistance to chloride ingress, and therefore...
 - it is recommended to carry out performance testing of a concrete at different temperatures prior to execution, in order to plan an optimum curing strategy