Fremtidens injeksjonsprosedyre: Testing og kontroll av materialegenskaper

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Innhold

- Introduksjon
- Valg av sementer for eksperimenter
- Test prosedyre og resultater
- Konklusjoner

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Introduction

- **Objective**
  - Investigate index properties of some of the typical cements/grouts
  - Present relationship between different parameters
  - Assist with the selection of type of cement for grouting

Introduction

- Behaviour of cement grouts under **true tunnelling conditions**
  - **Actual temperature** in Norwegian tunnels is about **7-10 °C**
  - **Actual water pressure** in tunnels depends on the depth/water table
  - Behaviour of grout is controlled by **w/c ratio, grain size distribution**, **additives,** …
  - We present results of lab tests on **3 types of cements, 4 w/c ratios,** at **8 °C and 20 °C**
  - We did not consider any **pressure** during curing of samples
  - Most tests are done on cement+water (no additives)

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List of lab tests utilized

- Grain size & specific surface area
  - Blaine finness
  - BET
  - Falling drop
- Viscosity
  - Marsh cone
  - Spread ring
  - Rheometer
- Stability and penetration of grout
  - Bleeding/water separation
  - Filtration test
- Setting time
  - Vicat needle
  - Calorimeter-hydration heat
- Strength
  - Uniaxial compressive strength (UCS)
- Permeability
  - Constant head perm test

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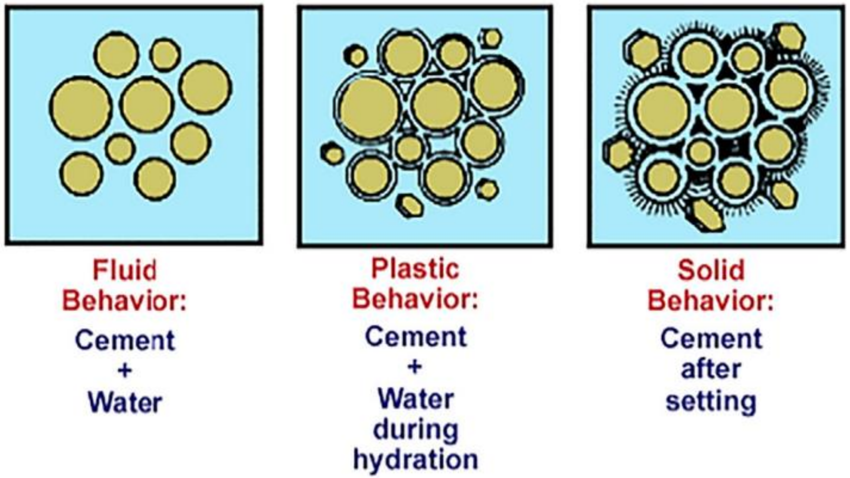
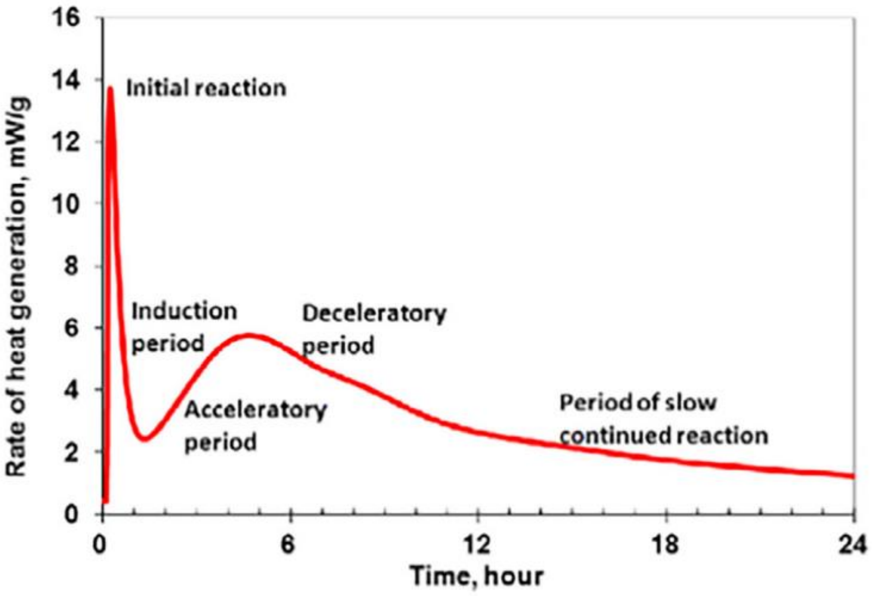
Properties of cement grout-developing with time/ curing



Nguyen, 2012



Hu et al., 2014

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Experimental work: seven cements

1. BASF MasterRoc MP650
2. BASF MasterRoc MP800
3. BASF MasterRoc MP900
4. Cementa Ultrafine 12
5. Cementa Microfine 20
6. Cemex Rapid
7. Norcem Industrisement

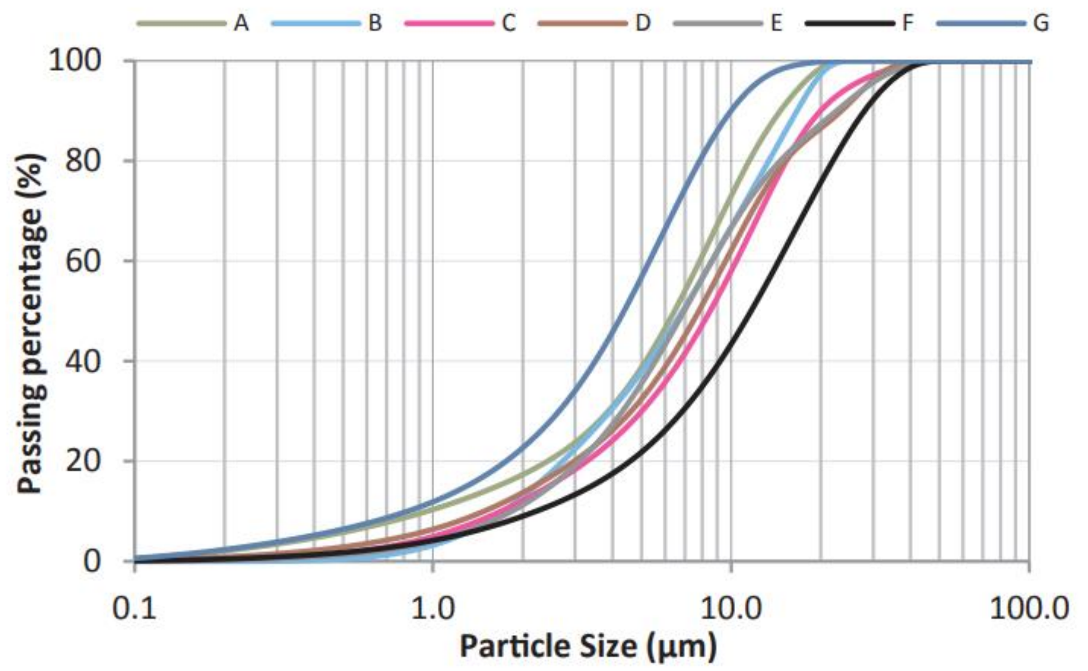

Fig. 1. Grain size distribution of cements commonly used in Norway for tunnel grouting (After Skjølsvold and Justnes, 2016).

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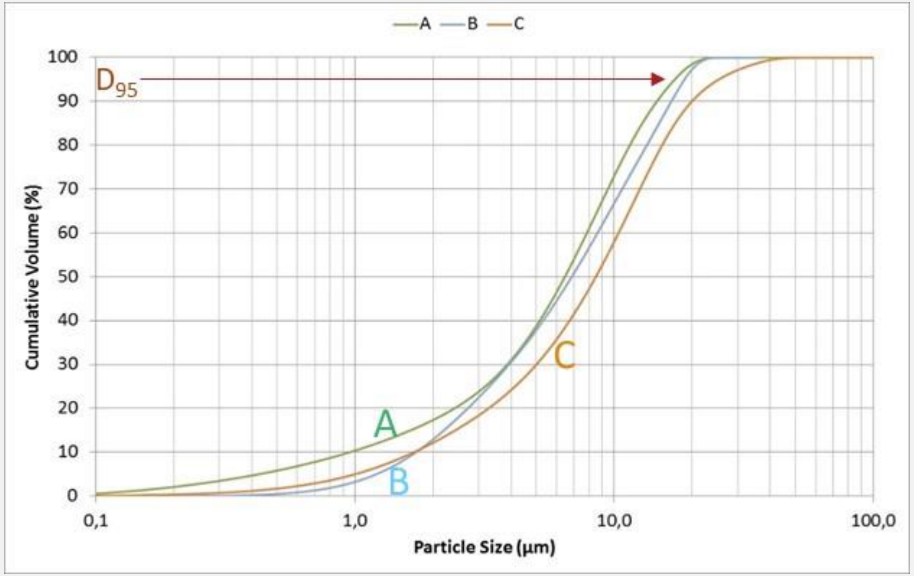
Cements used for this study

Norwegian Public Road Administration's Code of Process 025, standard grouting cement:

- particle size of about 20 µm
- D_{95}<40 µm



Physical properties of cements A, B and C.

Cement type	Density (g/cm^3)	Blaine fineness (m^2/kg)	Specific surface, BET (m2/kg)	D_{95} (µm)
Cement A	3.17	729	1880	17
Cement B	3.16	541	1580	18
Cement C	3.10	706	1930	25

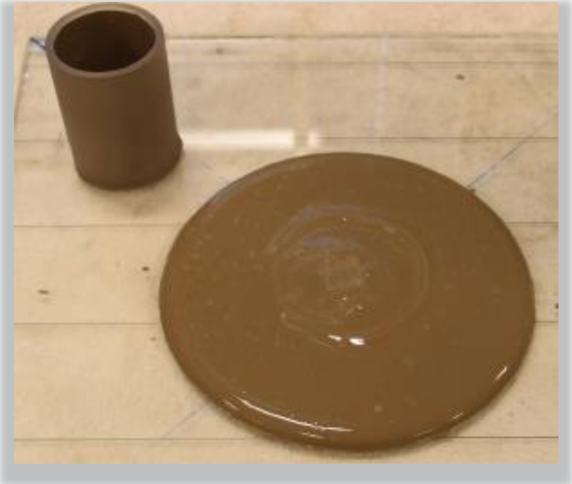
Falling drop indicated grain size of grout mix: 20-70 µm

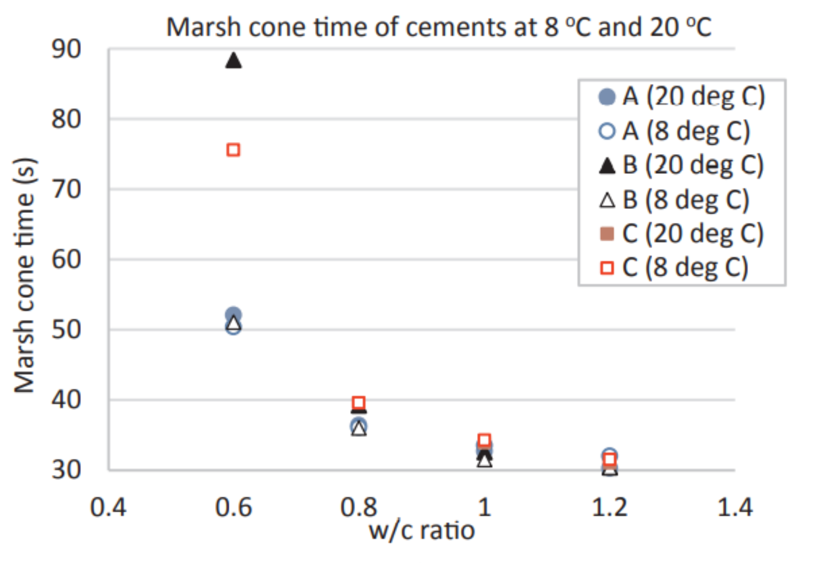
Cement blender, mix @ 2000 rpm, 2 min

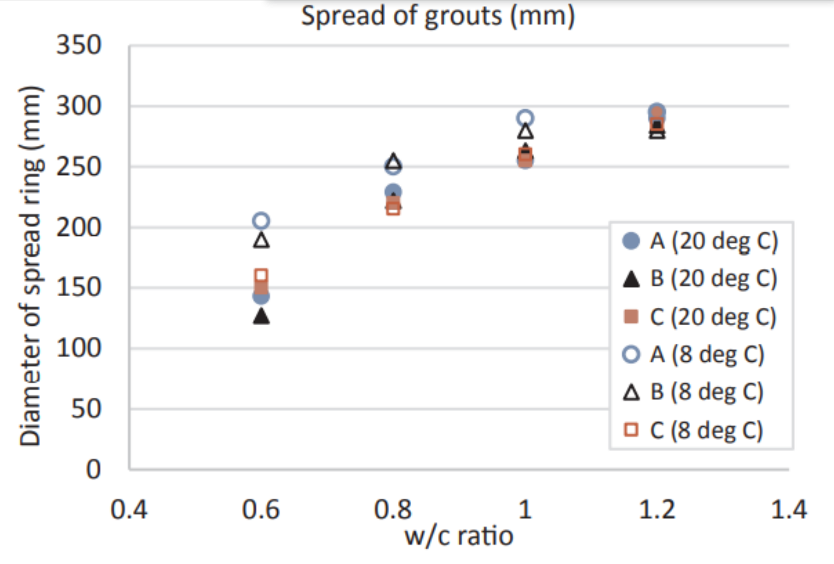
Viscosity

Marsh cone

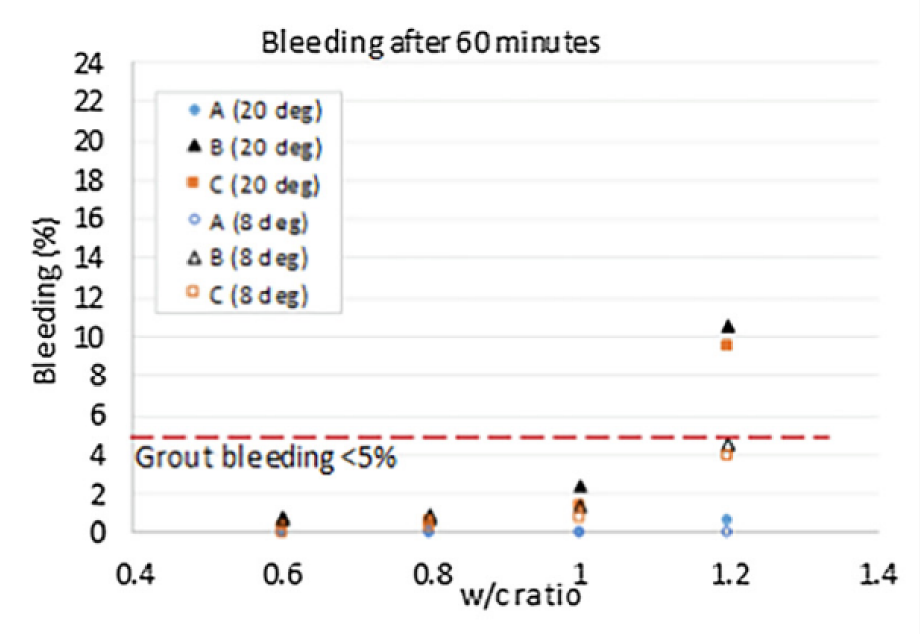
Spread ring

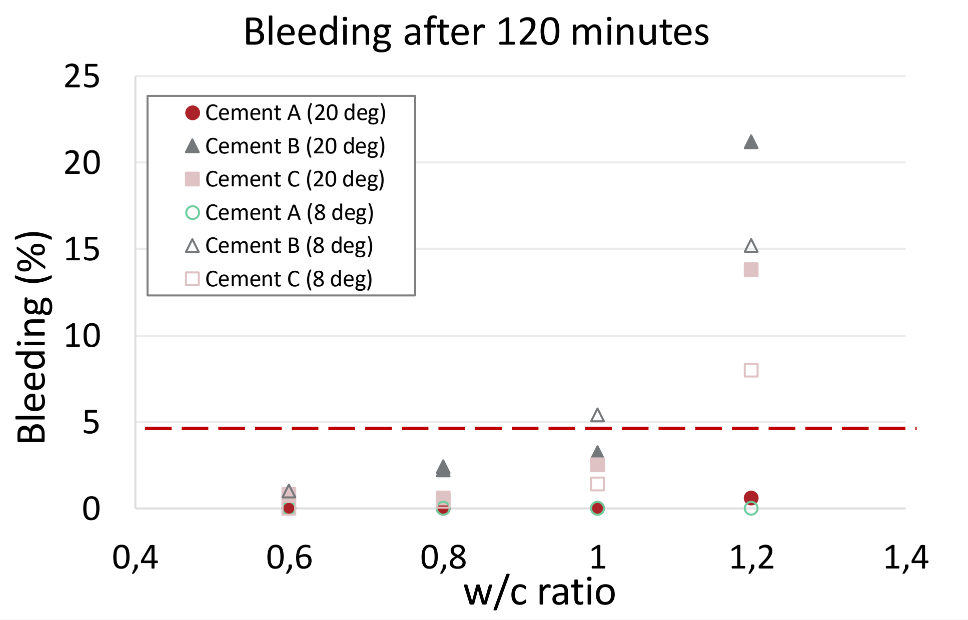




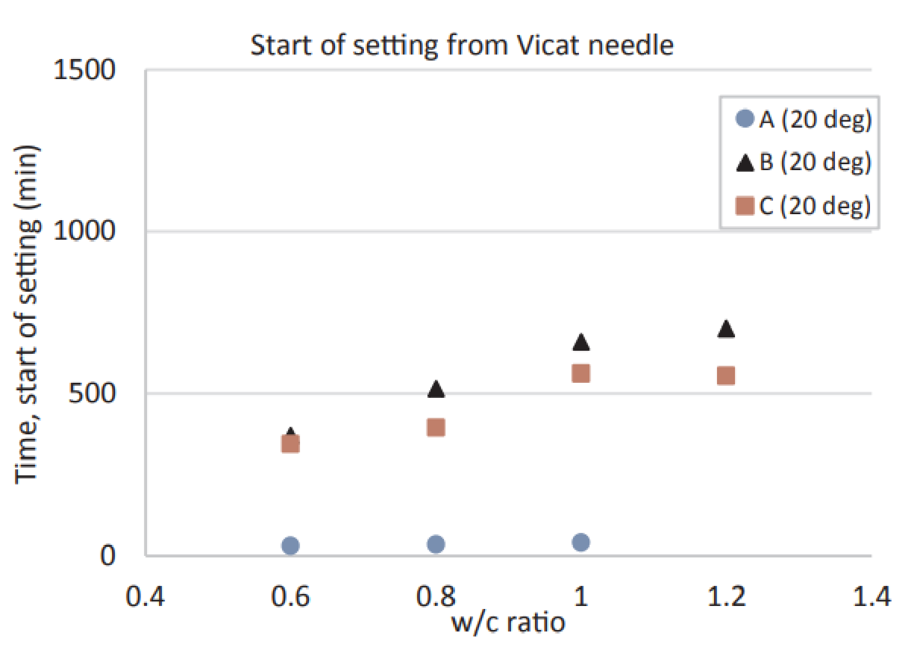


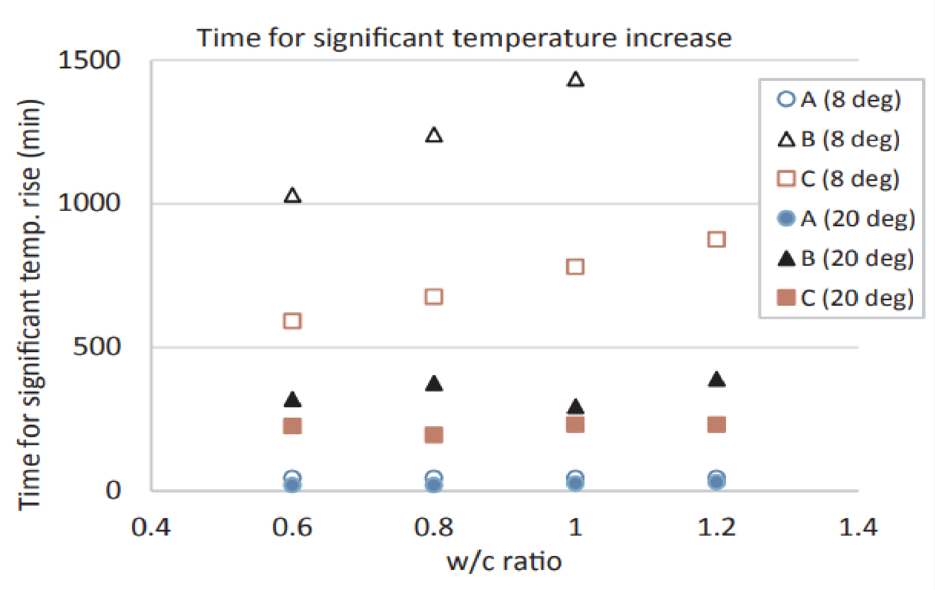
Bleeding (water separation)





Setting time

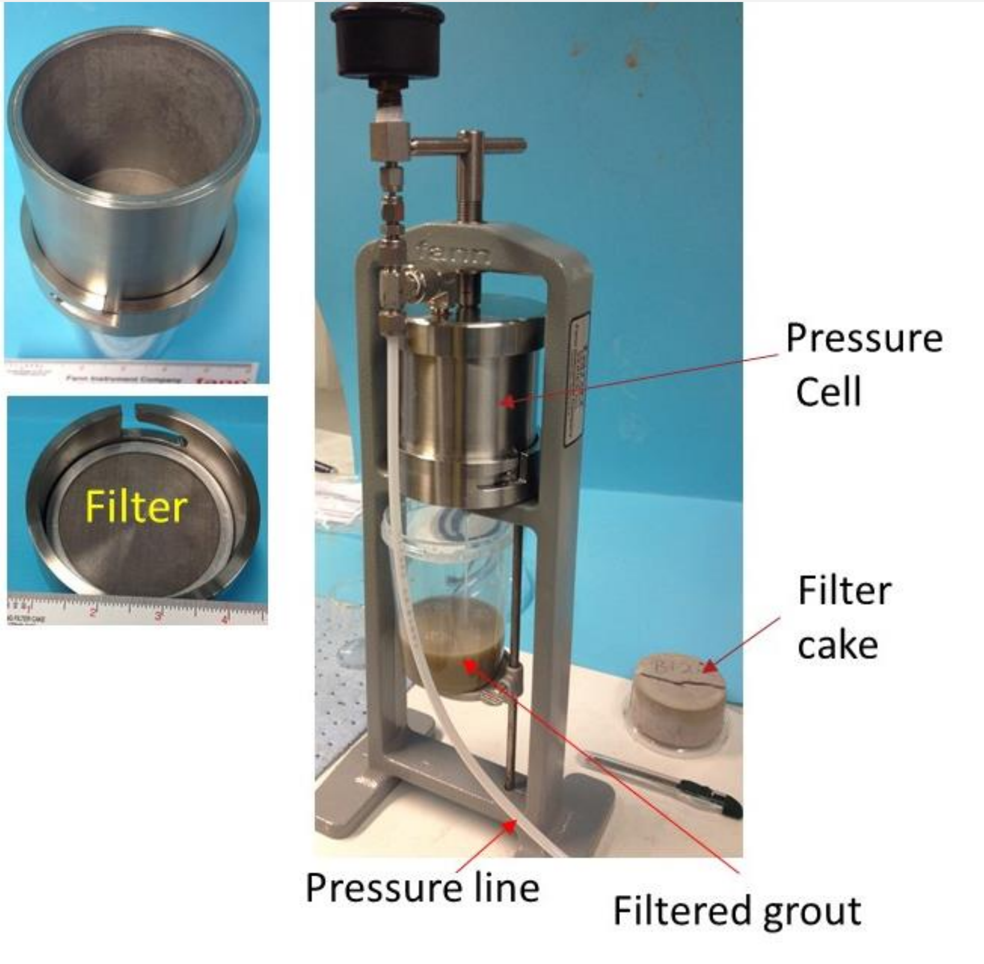




Filtration test: API Filter Press

Filter Press:

- Provides data related to penetrability of grout
- Pressure on the grout = 100 psi (7 bar)
- Measure filtration until air reaches the outlet
- Filter sizes used= 63 and 75 mic.



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Results of filtration test

Filtered grout: Cement C at 8°C,
filter size =75 µm

Filtered grout: Cement C at 20°C, filter size=75 µm

Filter cake and filtered material (mainly water)
for Cement B at 8°C, filter size=75 µm

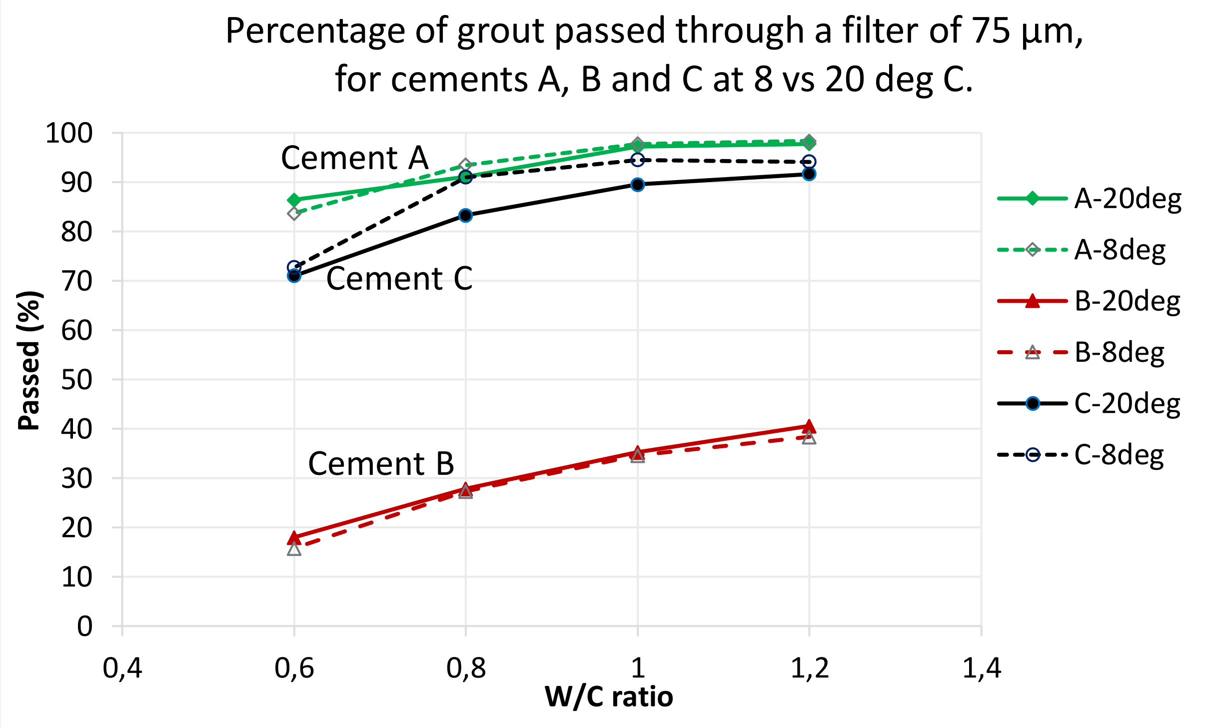
Comparison of filtration stability of different cements at 8ºC versus 20ºC

Passed percentage at 8ºC is not very different from 20ºC, slightly higher for cement C.

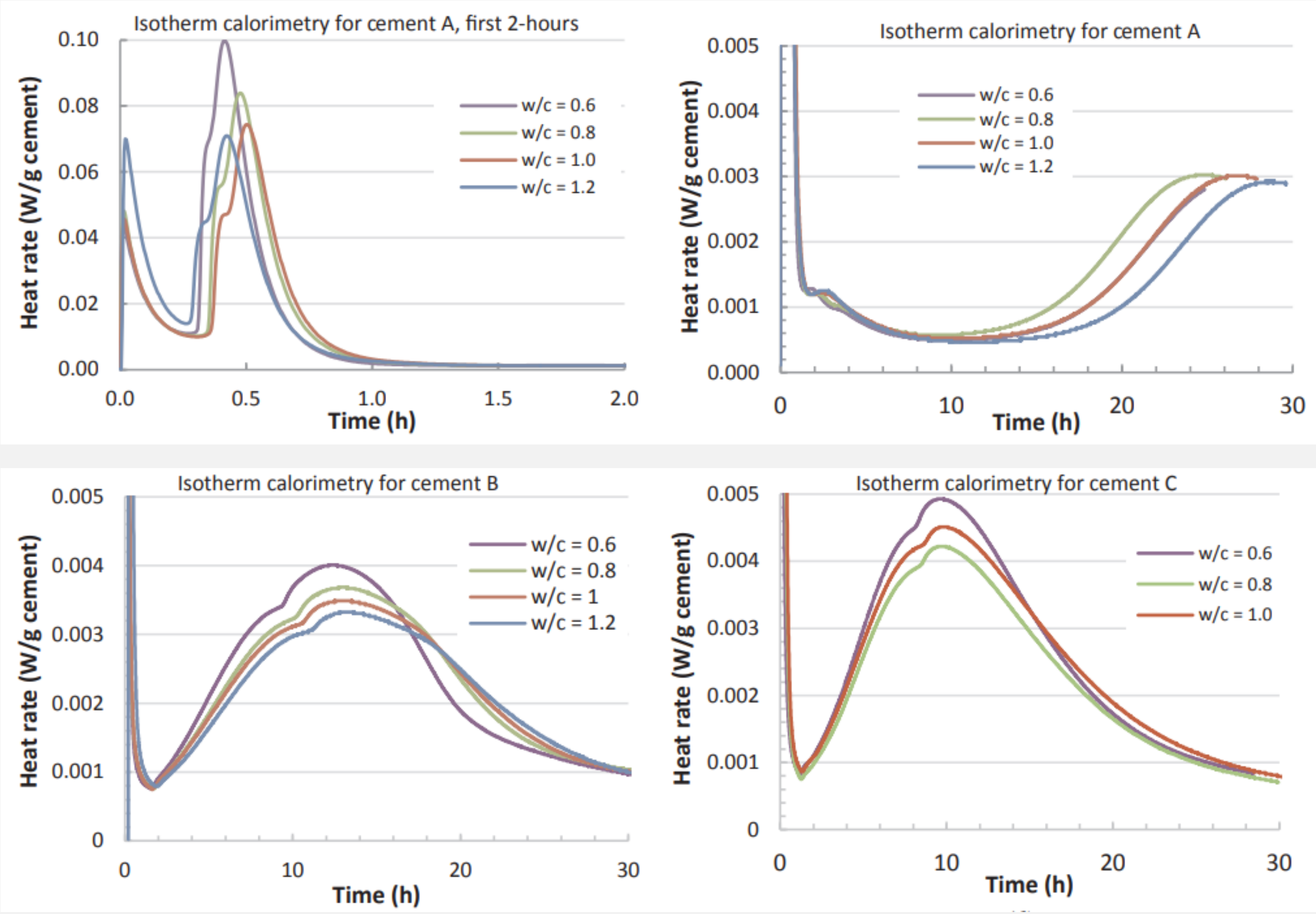
Cement A shows best penetration

Cement B has the lowest penetration

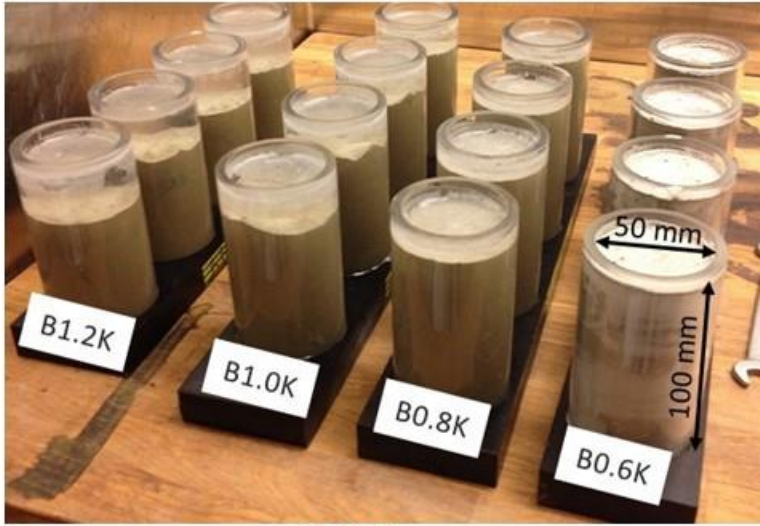
Passing percentage increases with increasing w/c ratio



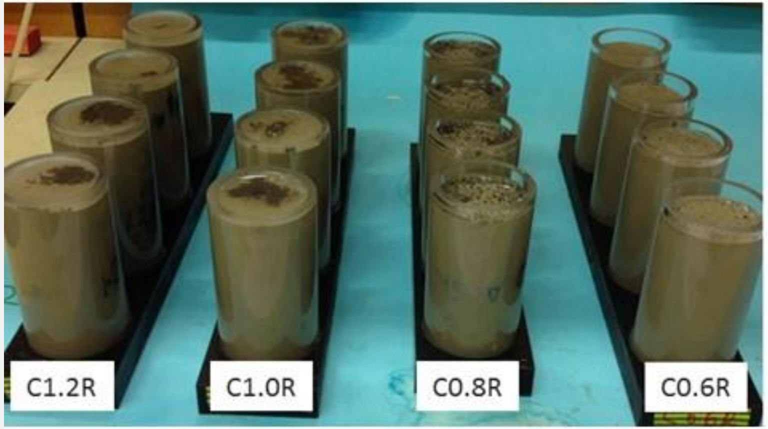
Heat of hydration for different cements at 20 deg C



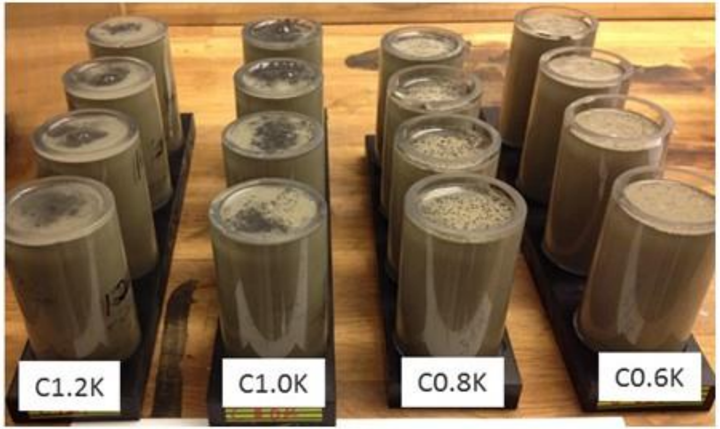
Strength testing (UCS)



8 °C



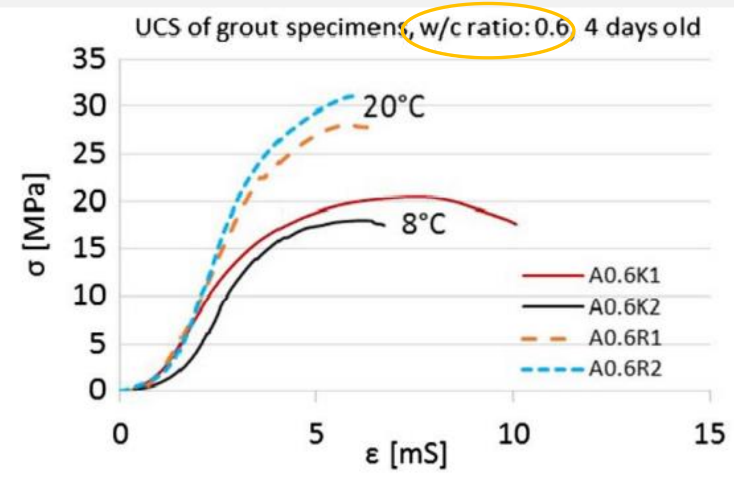
20 °C

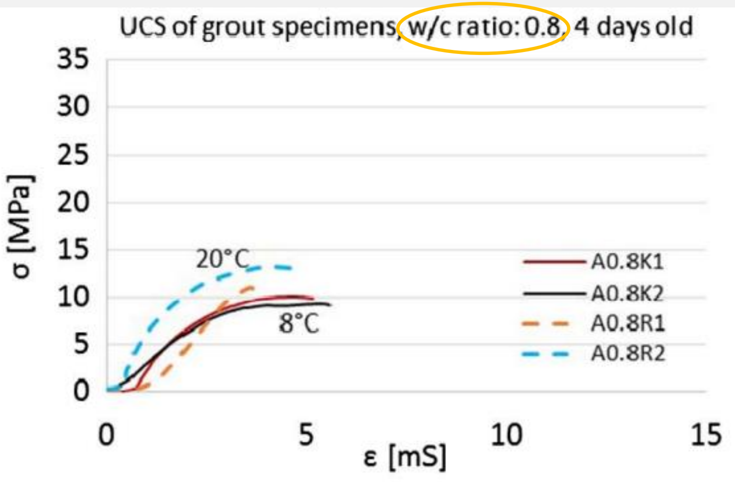


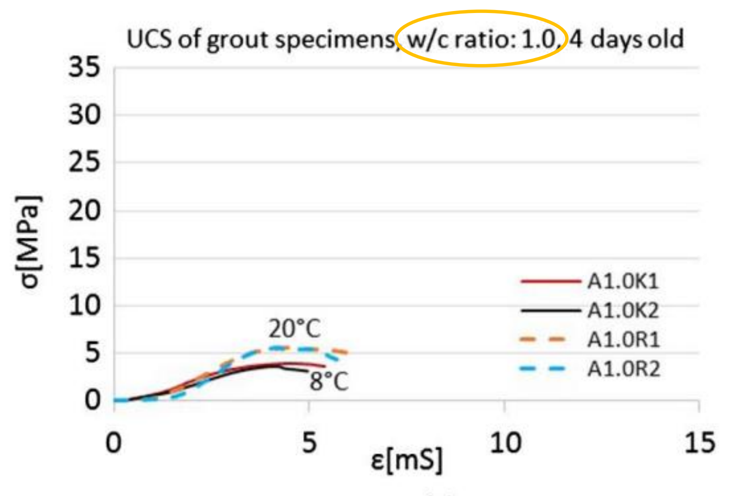
8 °C

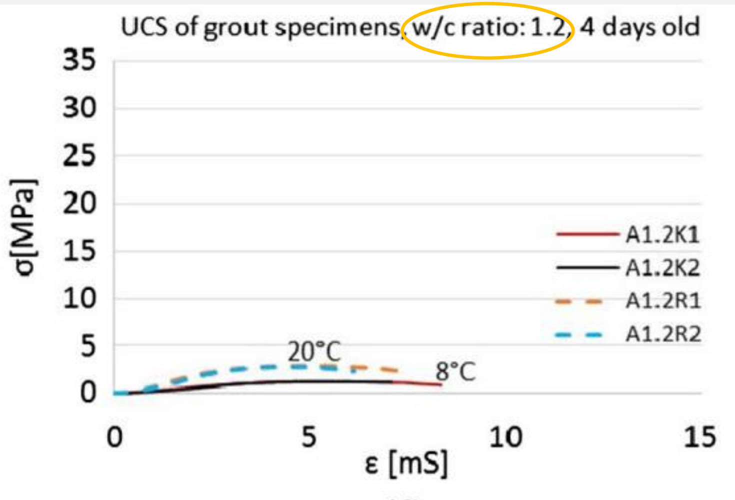
Test Results:

Uniaxial compressive strength of
- cement A
- cured 8ºC/20ºC
- 4 days old









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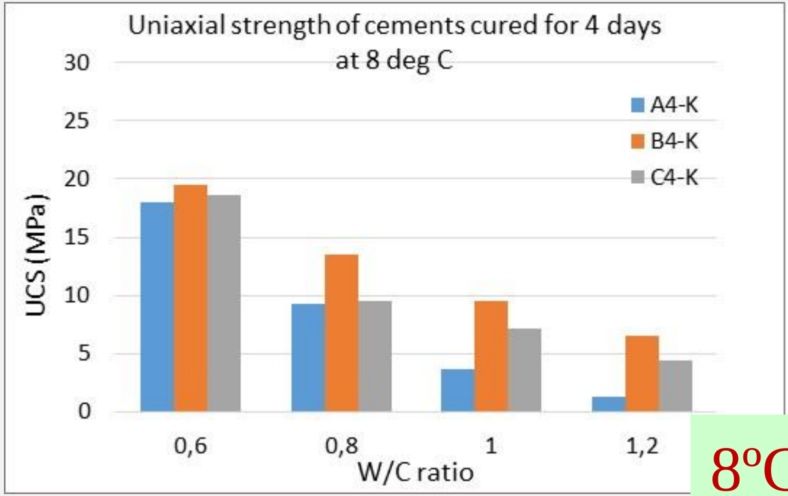
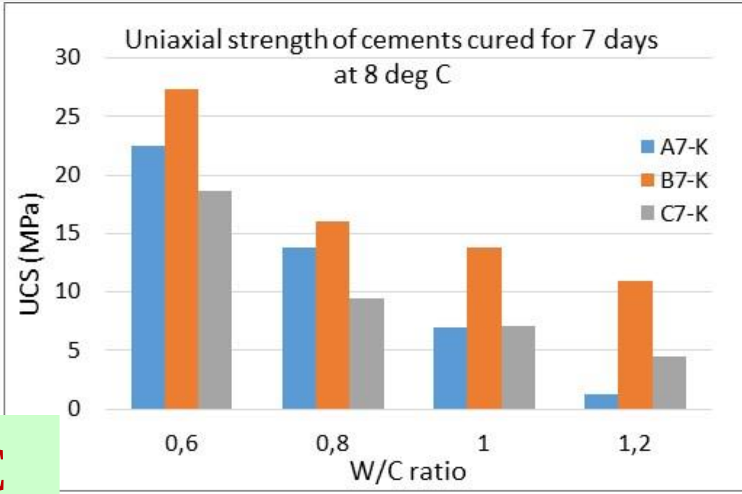
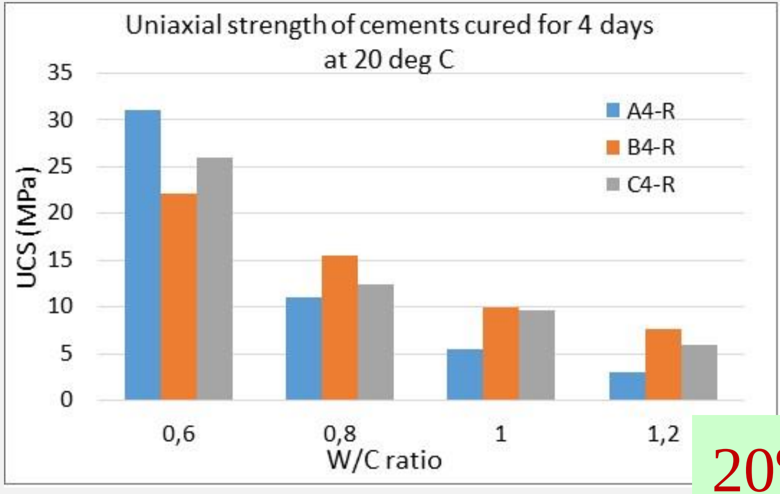
Uniaxial compressive strength of
- all cements
- cured 8ºC/20ºC
- for 4 & 7 days

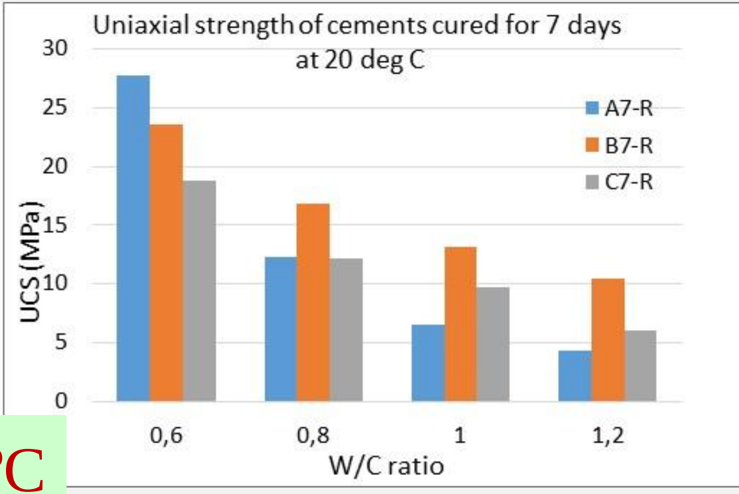
w/c > 0.4 water will not be bound by chemical reactions and contributes to increased porosity →decreased strength





8ºC





20ºC

Permeability of cured cement samples-7 days

	k (cm/s)	K (mD)
A1.2R	1,83E-07	1,83E-01
B1.0R	1,51E-10	1,51E-04
B1.2R	3,89E-11	3,89E-05
C1.0R	5,35E-10	5,35E-04

Permeability of non-fractured igneous rocks ≈ 1×10^{-2} mD

For strict water tightness: cement B &C are good, but cement A?

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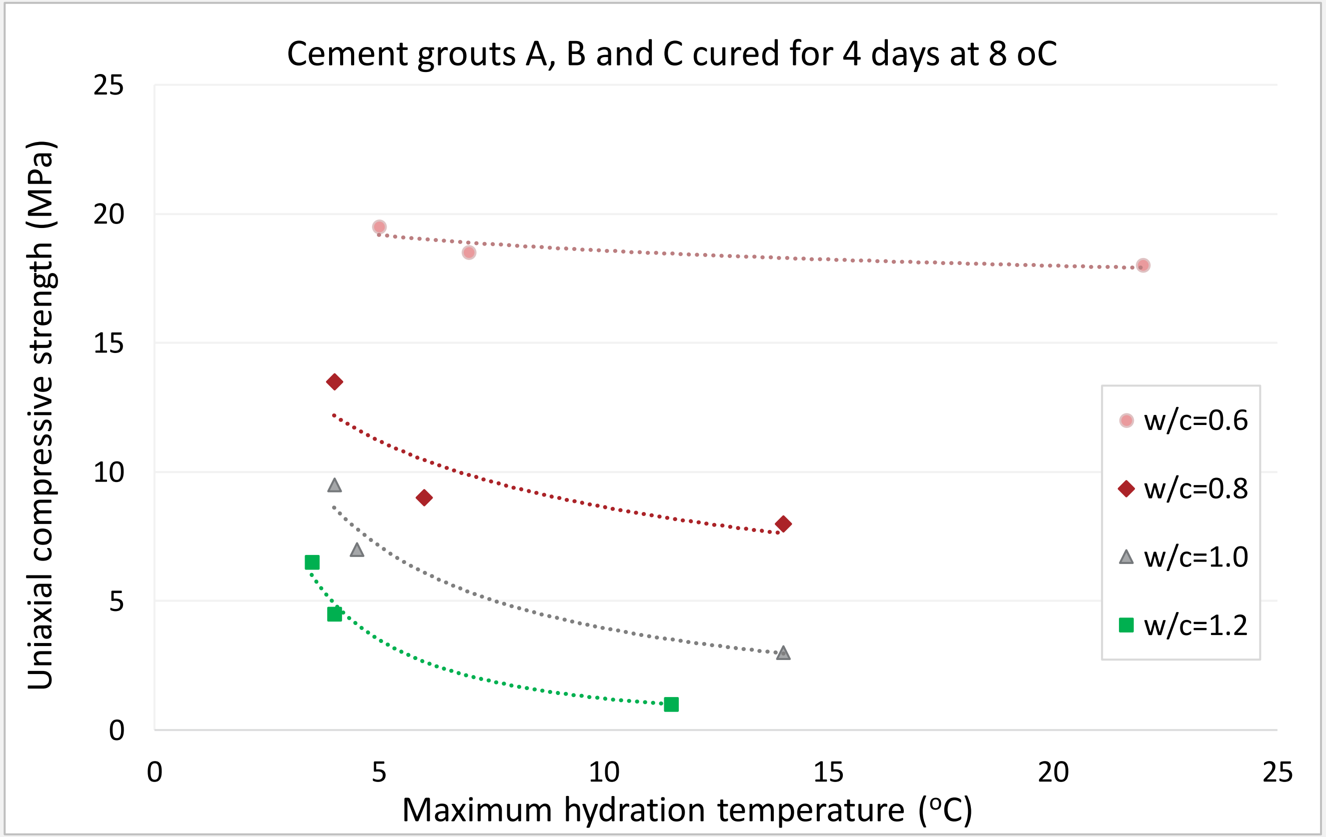
Hydration temperature versus strength



Comparison between the cements

Property / Cement	Bleeding	Filtration	Viscosity	Setting time	strength	Hydr. temp	Rank
A	●	●	●	●	◐	◐	●●●●●
B	--	--	●	--	●	●	●●●
C	◐	●	◐	◐	●	◐	●●●●

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Strength and filtration stability of cement grouts at room and true tunnelling temperatures

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Cements for tunnel grouting – Rheology and flow properties tested at different temperatures

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Summary (1)

- Bleeding, filtration, strength, etc. at high w/c ratios need to be seen **in combination** for the grout objective
- **Filtration stability** of cements seems to be independent of grout temperature, but is **controlled by w/c ratio**
- **Viscosity and strength** of (grout) samples **at 8°C is lower** than those cured at 20°C
- Correlation between the **heat produced during setting** of cement grouts indicates a **negative correlation with strength**.

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Summary (2)

- The results above suggest that there may be a need to evaluate **additional parameters** for an effective characterization of cement grouts for rock grouting purpose
  - e.g. cement A for best penetration
  - cement B for high strength, etc.

- Our results agree with Stille and Draganovic´, 2011: Grout **penetrability is the best for fine-grained cement**, better than the coarse or very fine-grained cements.

- The results of this study and the correlations suggested may also be used to **develop new types of cement products** that are more favorable for tunnel grouting.

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