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Concrete spalling by hydrogen jet fires

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Clean Hydrogen Partnership

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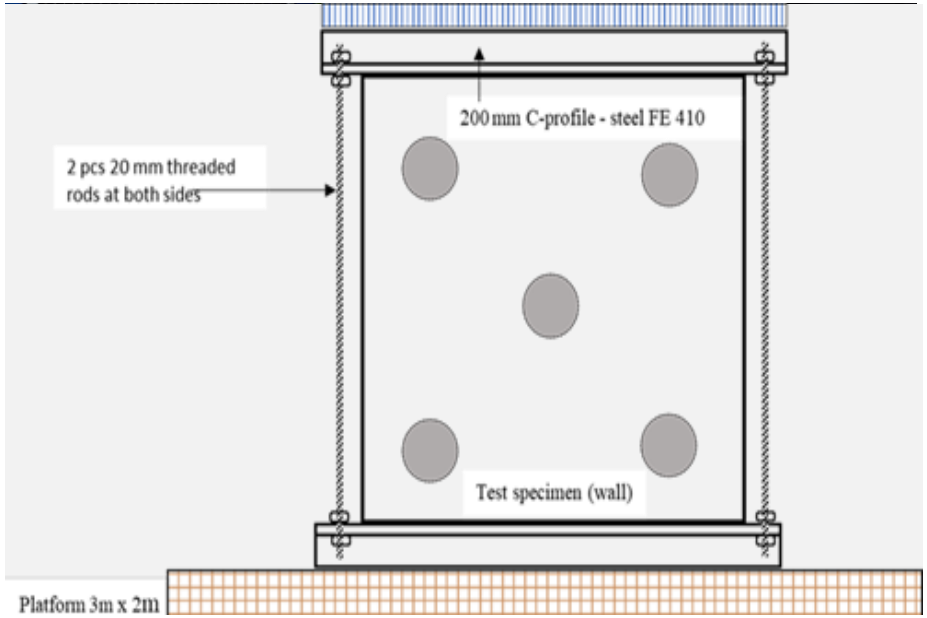
Experimental setups

Exposure by heat radiation and gas flames



Test setup for exposure with heat radiation:

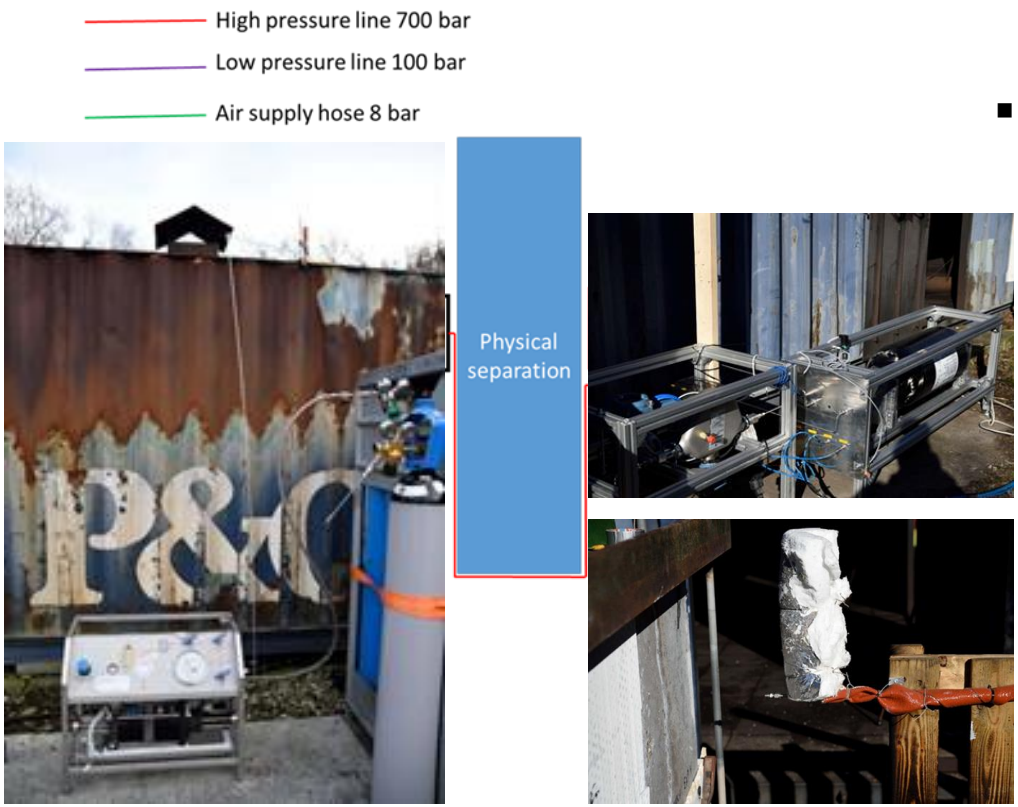
- Electrically heated furnace to test loaded concrete cylinders
- Through an opening in the furnace the concrete is exposed to the heat radiation of about 45 kW/ m^2 (@ 1000 ^oC)

Low pressure impinging propane flame setup:

- Test setup for tests of concrete wall elements in compression, with propane and hydrogen flame exposure
- A concrete wall 1000mm x 1000mm x 100mm. compression 1.2MPa

Experimental setups

High-pressure hydrogen setup

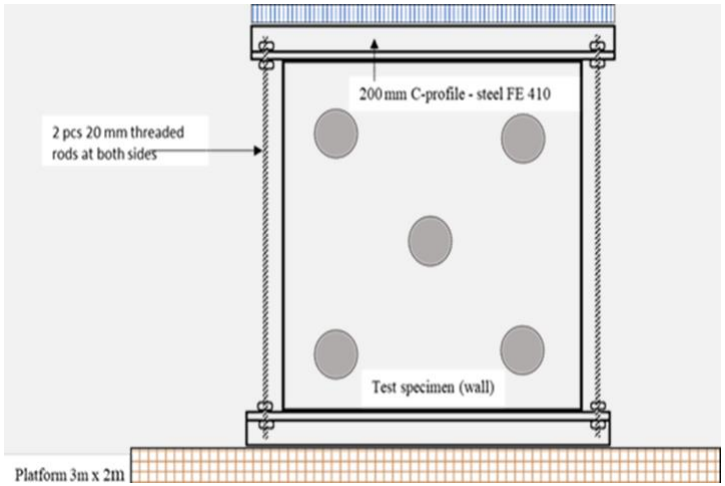


- Impinging hydrogen flame setup for exposure of a concrete wall

Wall dimensions 1000 mm x 1000 mm x 100 mm.

Compression load 1.2 MPa

Hydrogen at 700 bar, nozzle 3 mm



Concrete types investigated

Screening test with furnace setup

No	Characteristics	W/C ratio	MC	FA	PL	PP N or F	AG
A	Reference	0.45	0%	0%	-	0%	Sea
B	Dense	0.40	1%	0%	+	0% or 1%	Sea
C	Dense+	0.35	2%	2%	+	0% or 1%	Sea
D	Dense+ High strength	0.30	4%	0%	+	0% or 1%	Sea

Characteristics of the concrete types.

W/C=water/cement ratio, MC=micro-silica, FA=fly ash, PL=plasticizer, PP=polypropylene (N= no fibres, F= fibres), AG=aggregates, %=w/w%

Concrete screening results

Selection of concrete types

Sample	Spalling	Debris (g)	Remark
A-N-7	Yes	0.5	8 tests – 2 spallings
A-N-8	yes	2.7	
B-N-1	yes	60.9	5 tests – 2 spallings
B-N-4	yes	0.5	
B-F	NO		5 tests – no spalling
C-N-4	Yes	13.0	5 tests – 2 spallings
C-N-5	yes	27.6	
C-F	NO		5 tests – no spalling
D-N-2	Yes	22.8	5 tests – 4 spallings
D-N-3	Yes	18.6	
D-N-4	Yes	16.5	
D-N-5	yes	30.5	
D-F	NO		5 tests – no spalling

- X-N = no PP fibres
- X-F = with PP fibres

Concrete types for the wall elements

Selected concrete types after screening

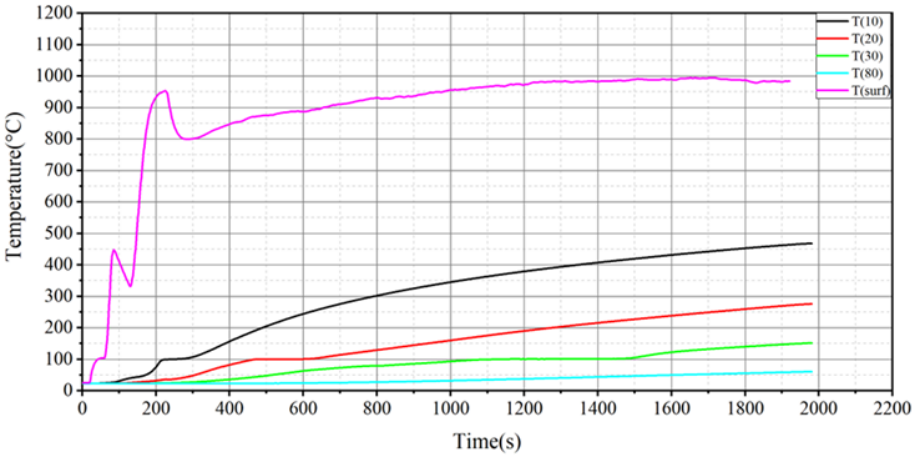
Wall	Concrete	Characteristics	W/C ratio	MC %	FA %	PL	PP %	AG
1	B	Dense	0.40	1	0	+	1	Sea
2	C	Dense+	0.35	2	2	+	1	Sea
3	D	Dense+ High strength	0.30	4	0	+	1	Sea

Characteristics of the concrete types casted as a 1000 mm x 1000 mm x 100 mm walls.

W/C=water/cement ratio, MC=micro-silica, FA=fly ash, PL=plasticizer, PP=polypropylene, AG=aggregates, %=w/w%

Results

LPG exposure



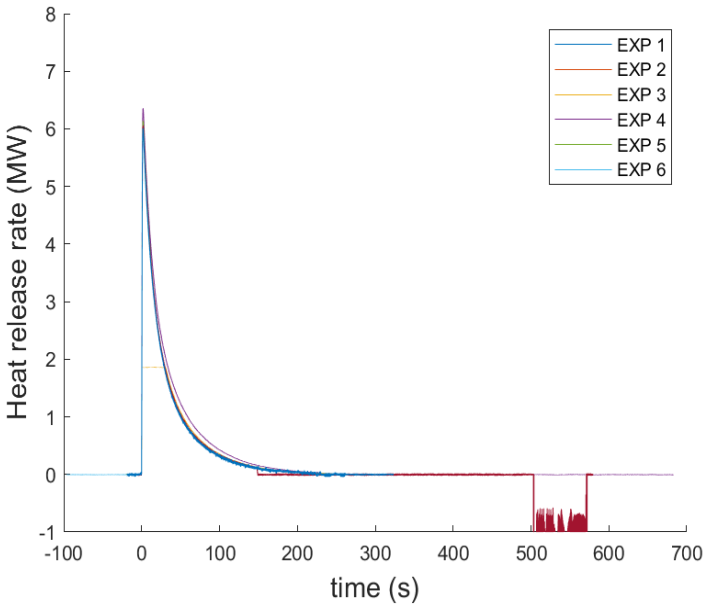
- Temperature profiles for wall element 2 – WE2, w/c=0.35, concrete C (test date 29-6-2021, start at 11:29).
- T @depths: 0mm, 10 mm, 20mm, 30 mm and 80 mm) inside the concrete
- HRR average = 13.2 KW/s
- Total energy released in 1800 s: 23.8 MJ

Wall element	W/C	Concrete type	PP-Fibers	Gas flow (g/min)	HRR flame (kW)	Spalling	Cracks
WE1	0.40	B	Yes	16.50	12.65	No	Fine
WE2	0.35	C	Yes	17.75	13.53	No	Fine
WE3	0.30	D	Yes	17.60	13.49	(No)*	Fine

Results

Hydrogen impacts

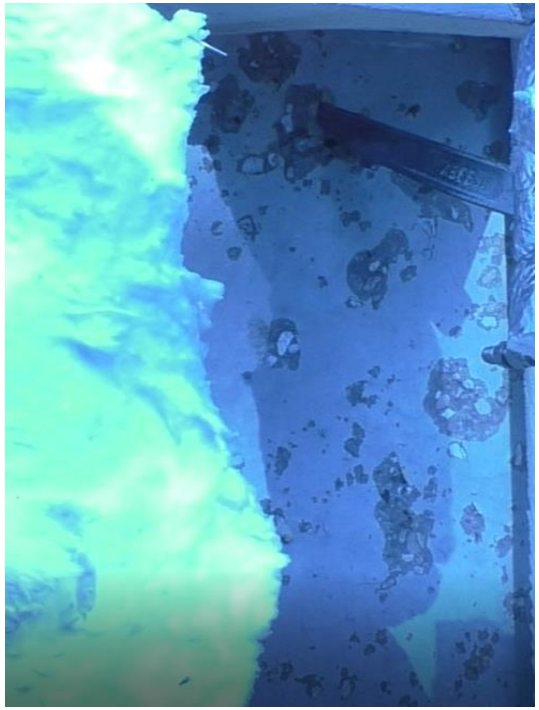
- Amount of hydrogen: 1.46 kg
- Release time: 200 s
- Total energy released in 200 s: 207.1 MJ
- HRR average_200s = 1.04 MW
- HRR_peak = 6.3 MW

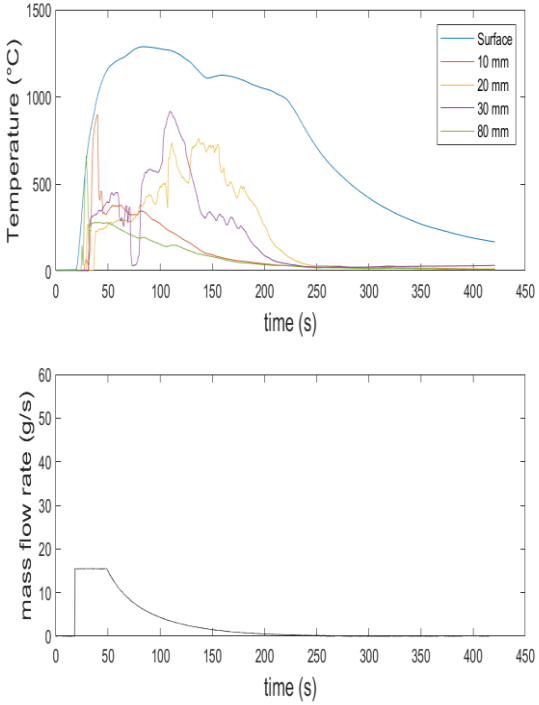


Wall element	W/C	Concrete type	PP-Fibers	Peak Gas flow (g/s)	Peak HRR flame (MW)	spalling	Cracks
WE1	0.40	B	Yes	53	6.2	No	Fine
WE2	0.35	C	Yes			yes	Fine
WE3	0.30	D	Yes			yes	Fine

Results

Hydrogen impacts wall 3 concrete type D



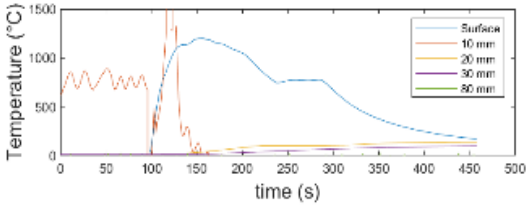


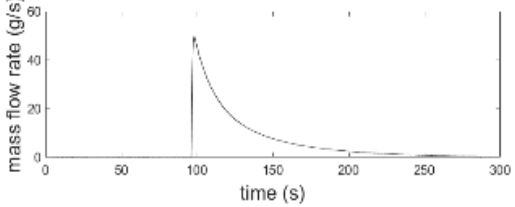
Exp 1
Test date 2-3-2022 morning

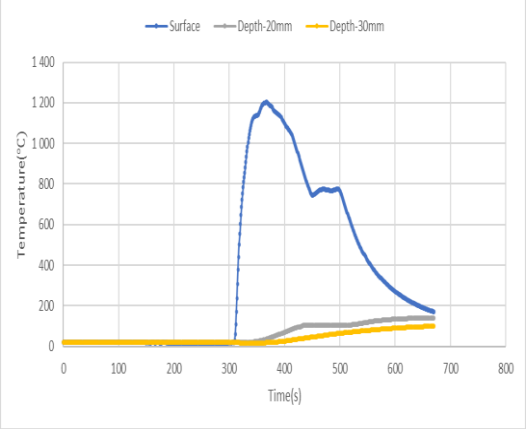
Exp 2
Test date 2-3-2022 afternoon

Results

Hydrogen impacts wall 2 concrete type C





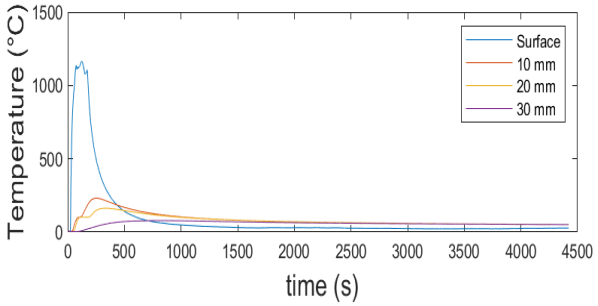


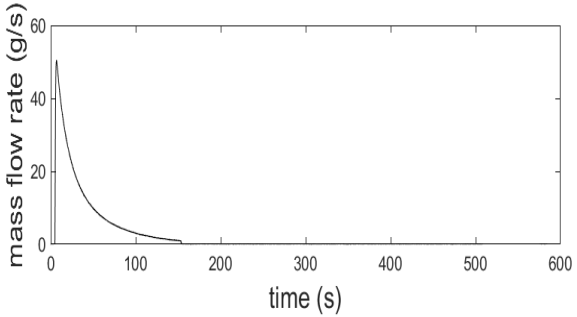
Exp 3
Test date 3-3-2022 morning

Exp 4
Test date 3-3-2022 afternoon

Results

Hydrogen impacts wall 1 concrete type B





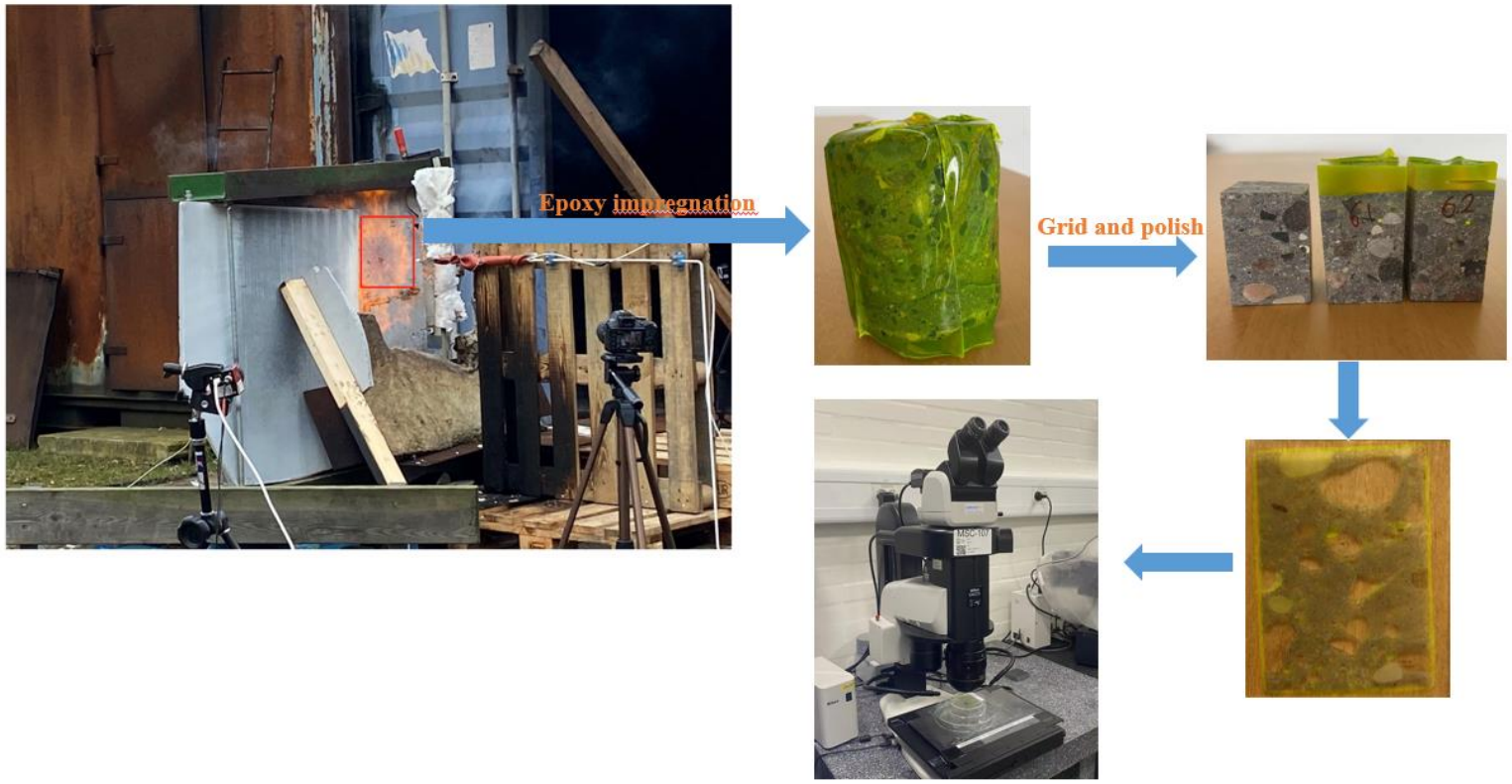
Exp 5
Test date 4-3-2022 morning

Exp 6
Test date 4-3-2022 afternoon

Results

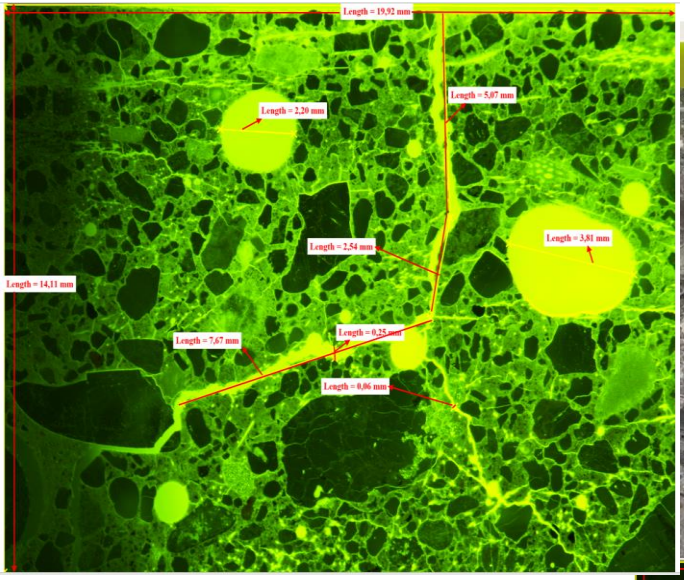
Hydrogen – analysis of material cracks

- Testing procedure

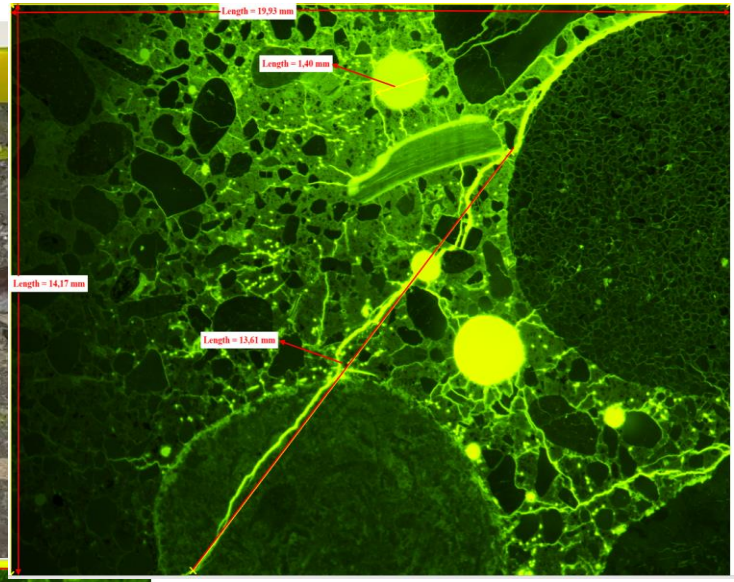


Results

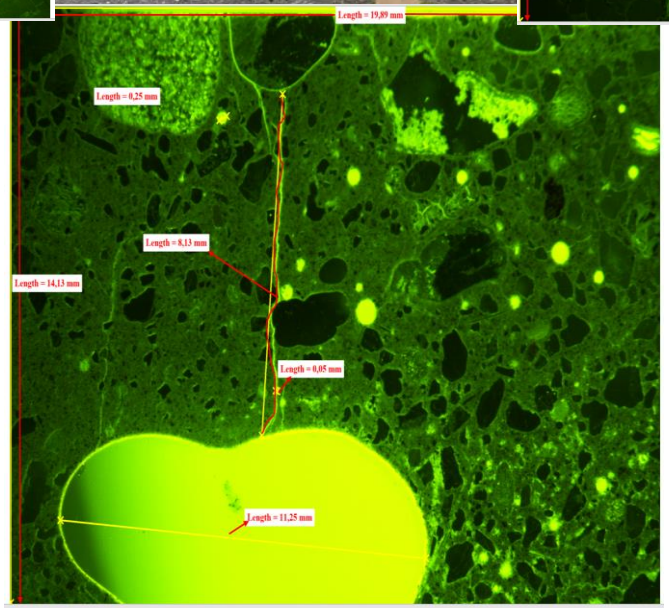
Crack analysis



Sample 3-1



Sample 3-2



Sample 3- bottom

Results

Crack analysis

sample	Number of pores	Pore area ratio (%)	Total area of major cracks (cm^2)	Major cracks area ratio (%)
3-bottom (ref.)	253	8.1	0.003	0.023
3-1	334	3.1	0.025	0.184
3-2	380	20.2	0.038	0.279
2-bottom (ref.)	224	1.4	0	0
2-1	175	1.1	0.013	0.099
2-2	293	2.5	0.016	0.12

Conclusions for hydrogen exposure

Concrete types B, C, D with PP fibres

- Surface temperature about 1200 C for H2 compared to 950 C for LPG (over 1800s)
- Some surface spalling is observed for the more dense concrete types C and D , not for B
- Major cracks -Impact on concrete core depth is about 1.8cm deep,

  for an impingning initial 6 MW hydrogen flame lasting for 200s (nozzle 3mm; 1.02 kg Hydrogen)
- Longer lasting hydrogen flames using a larger amount of hydrogen and/or smaller nozzle sizes may lead to an increased heating of the concretes raising the temperature at greater depth inside the concrete.

See also Contribution from HSE Sara Bergin later today

Thank you for listening
Frank Markert
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Acknowledgements

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