
PFPNet Conference 2024

# Hytunnel: Effect of hydrogen jet fires on the erosion of tunnel road and lining materials

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# Hytunnel

## Overview of project

- Aim: To inform on safety aspects relating to hydrogen so as to facilitate introduction of hydrogen vehicles into the transport network
- Method: Investigate hydrogen behaviours in confined spaces such as traffic tunnels and underground car parks or garages
- Modelling and experimental methods applied
- Multiple aspects e.g. hydrogen propagation through tunnel, applicability of existing safety features


Consequences of Mont Blanc tunnel in 1999.

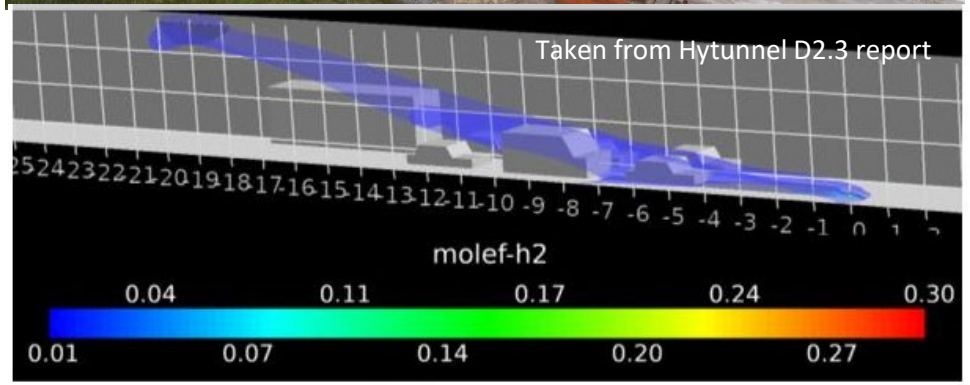
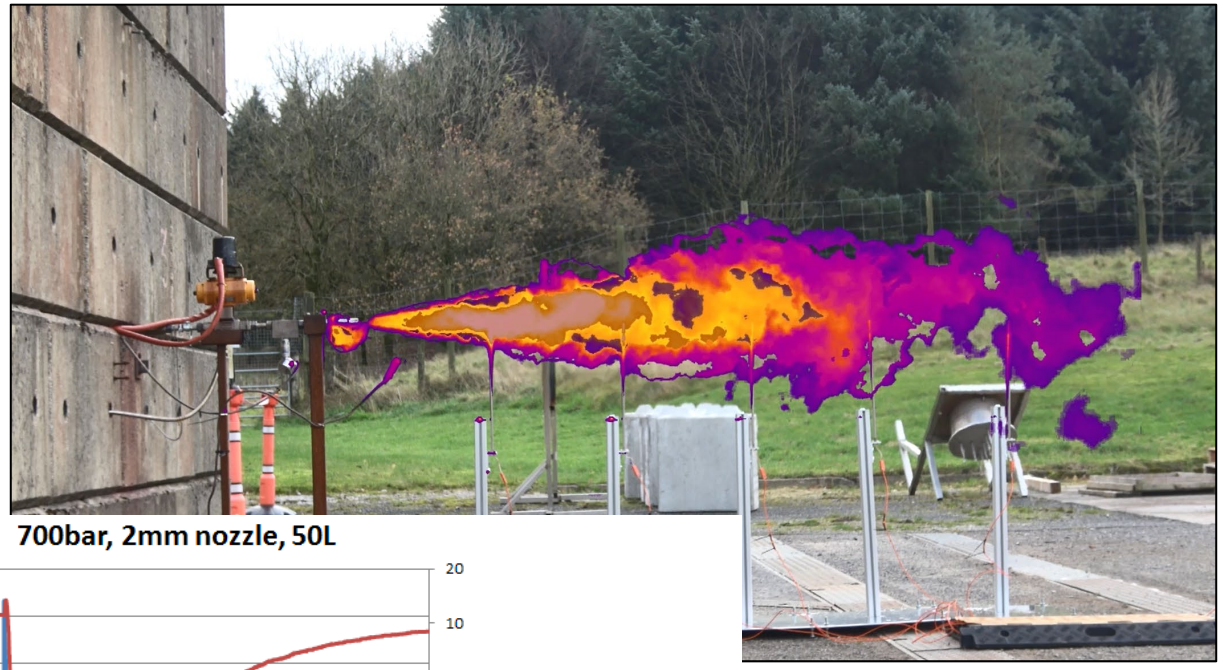




*Figure 3-32. Concentration decay along the tunnel at different times, iso-surface of 1% concentration and the contours across the centreline of the release in range 1-30%.*

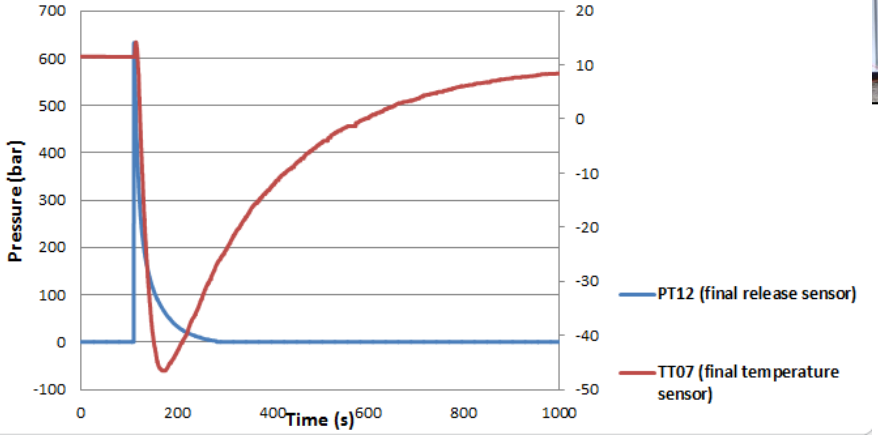
# Erosive effects of hydrogen jets on tunnel materials (Subtask 3.4.4)

## Two aspects: nature of jet and effect on concrete

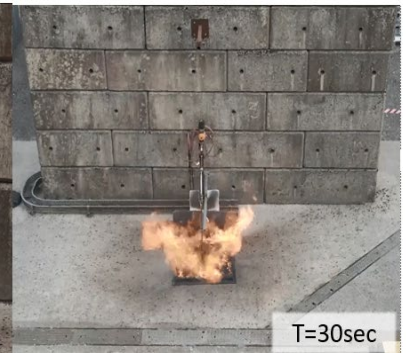
- blowdown characteristics, flame temperature, pressure



700bar, 2mm nozzle, 50L




- spalling, thermal effects, potential structural degradation.

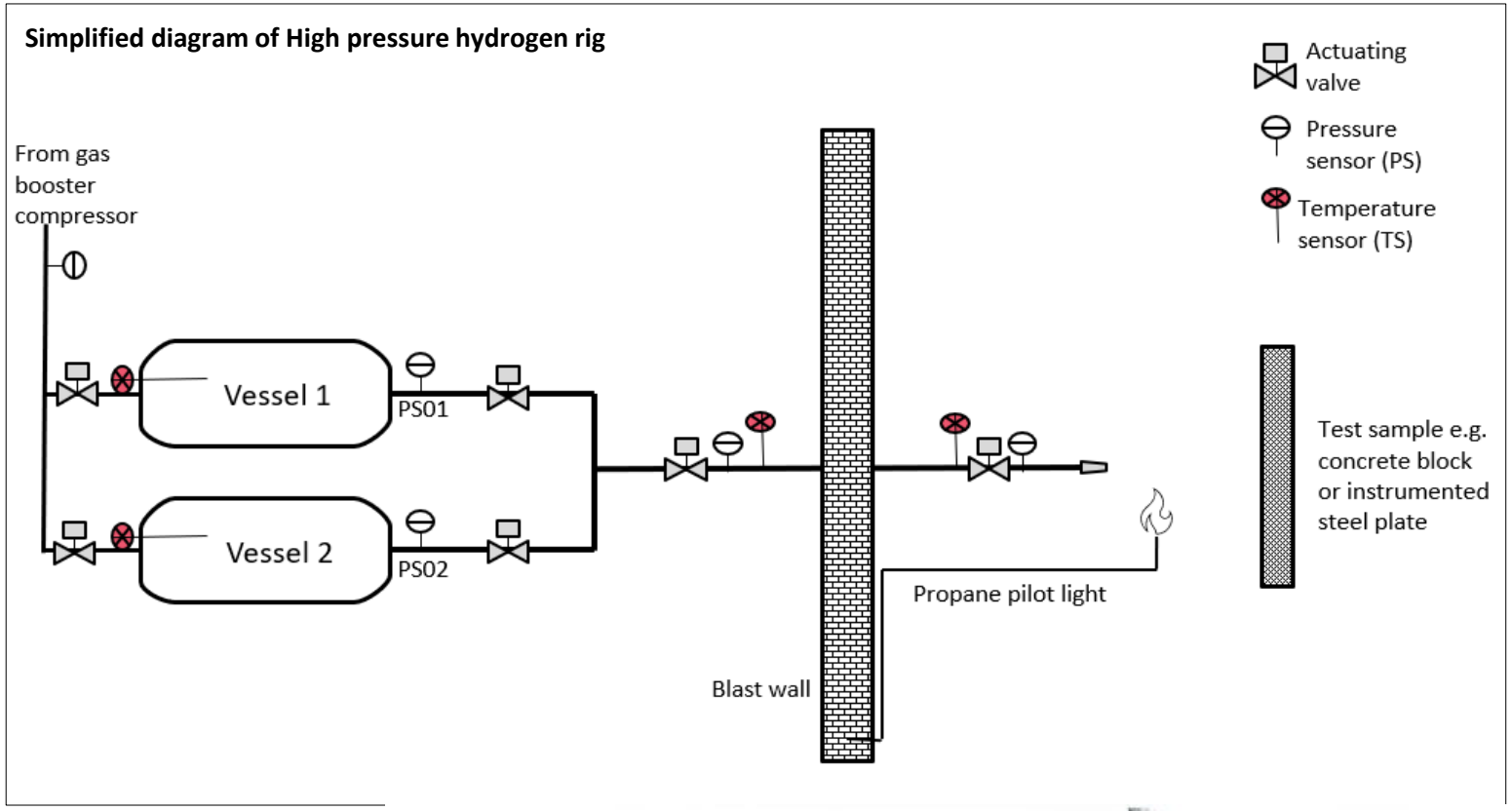



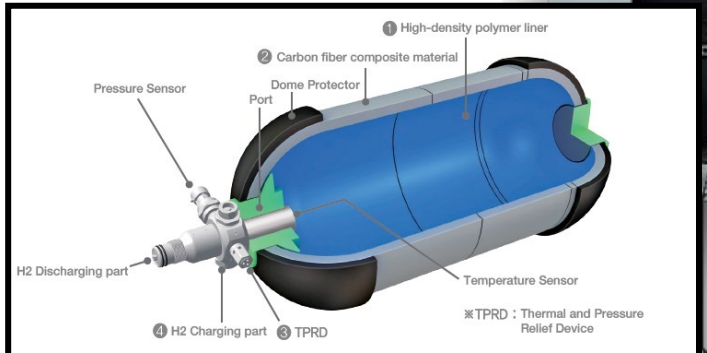
# Overview of setup

High pressure hydrogen rig

Still from hydrogen release onto concrete sample

**Simplified diagram of High pressure hydrogen rig**




Toyota Mirai hydrogen fuel tank (www.car.nulisen.com)

# Test matrix – release scenarios

- Free jet release – temperature measurements made along the axial length of an unimpeded jet.

- Impeded jet release – jet impinged onto two sensing plates; instrumented with pressure and temperature sensors

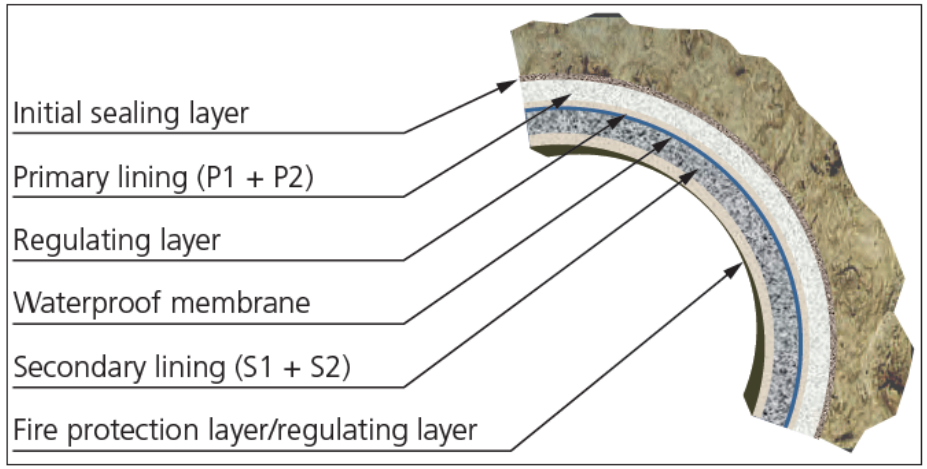
- Impeded jet release – jet impinged onto structural samples. Erosive effects investigated using imaging and post-test material analysis


# Factors affecting erosion of structural material

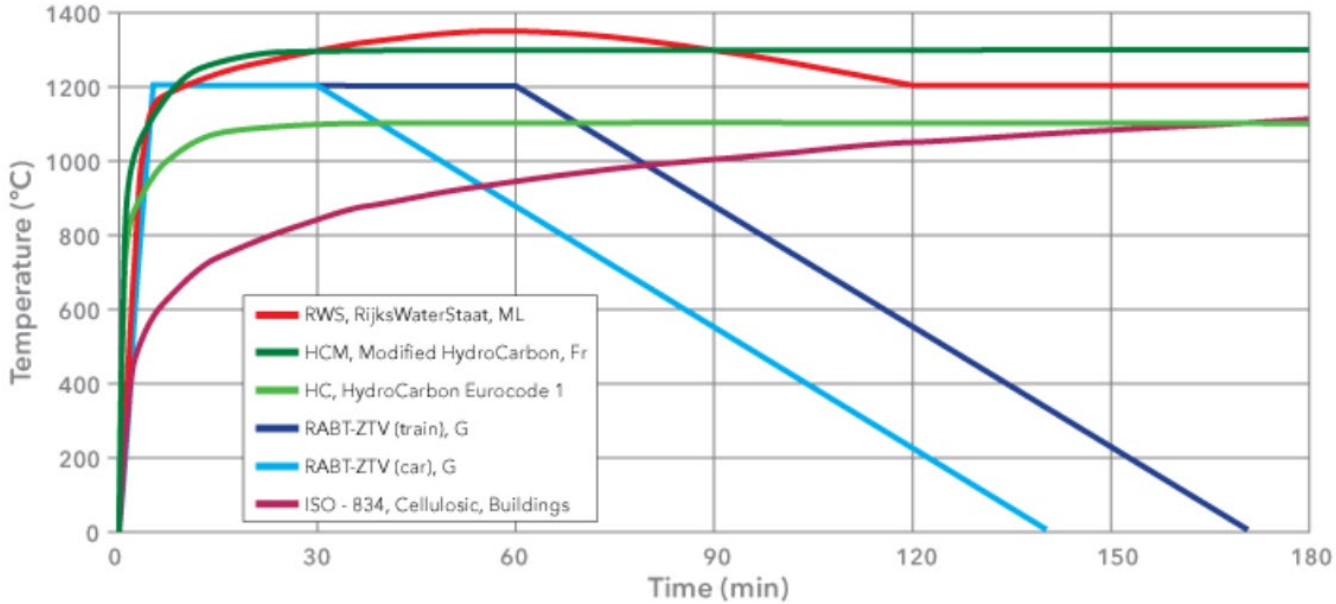
## Concrete sample composition

- Concrete strength >45MPa compressive strength
- Moisture content >3% by weight
- Addition of polypropylene fibres
- Permeability
- External compression

| | High strength |
|---|---|
| Concrete Grade | ≈50 MPa) |
| water/cement (w/c) ratio | 0.45 |
| Microsilica | No |
| Fly ash (cement sub) | Improve strength, reduce porosity |
| Plasticiser | Water reducing admixture used |
| PP fibres | Yes (12 mm) |
| Aggregates | Land (0-20 mm) |



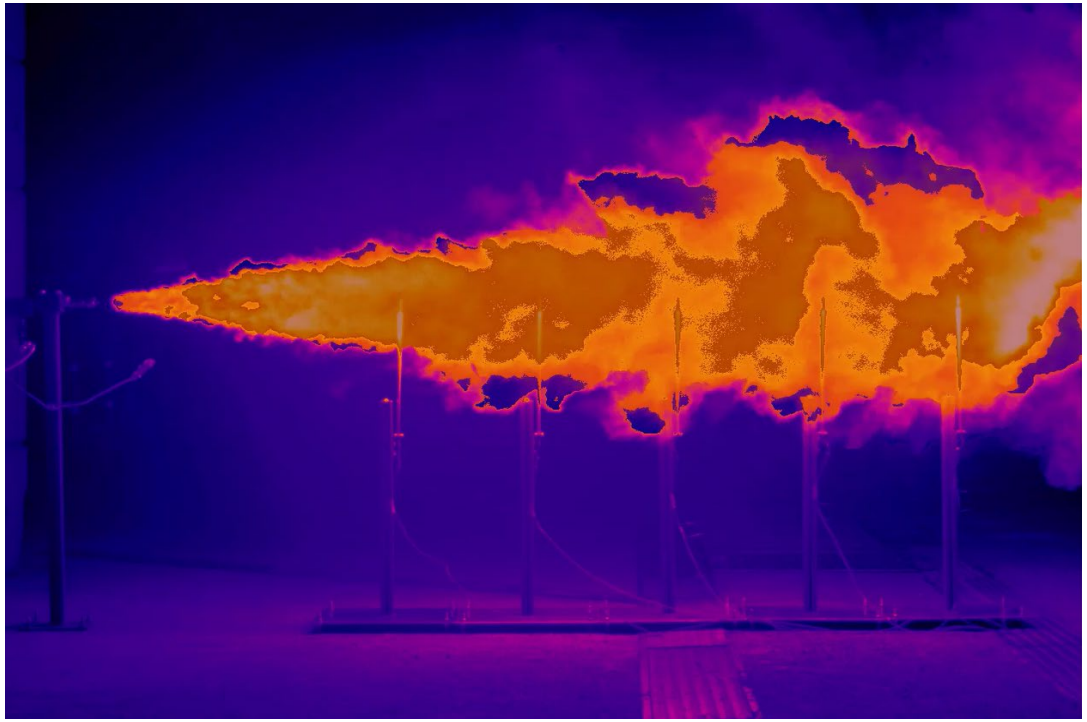

**Tunnel design for the London Elizabeth east-west railway line**




**Typical fire curves; samples exposed to a specific temperature profile over a defined time, aiming to mimic scenarios e.g. RABT-ZTV (car) simulates a hydrocarbon fuelled car fire within a tunnel** https://www.promat.com/en/

# Free jet

## 2mm nozzle, 700 bar, 50L



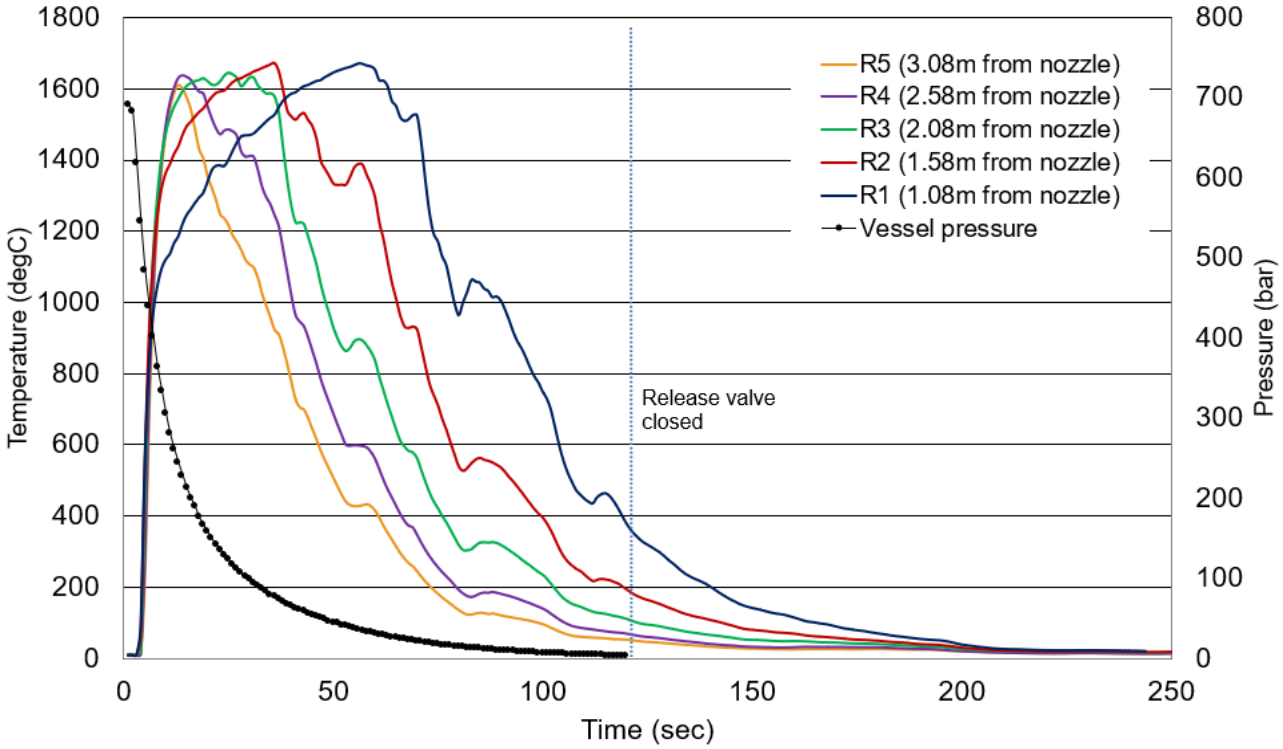
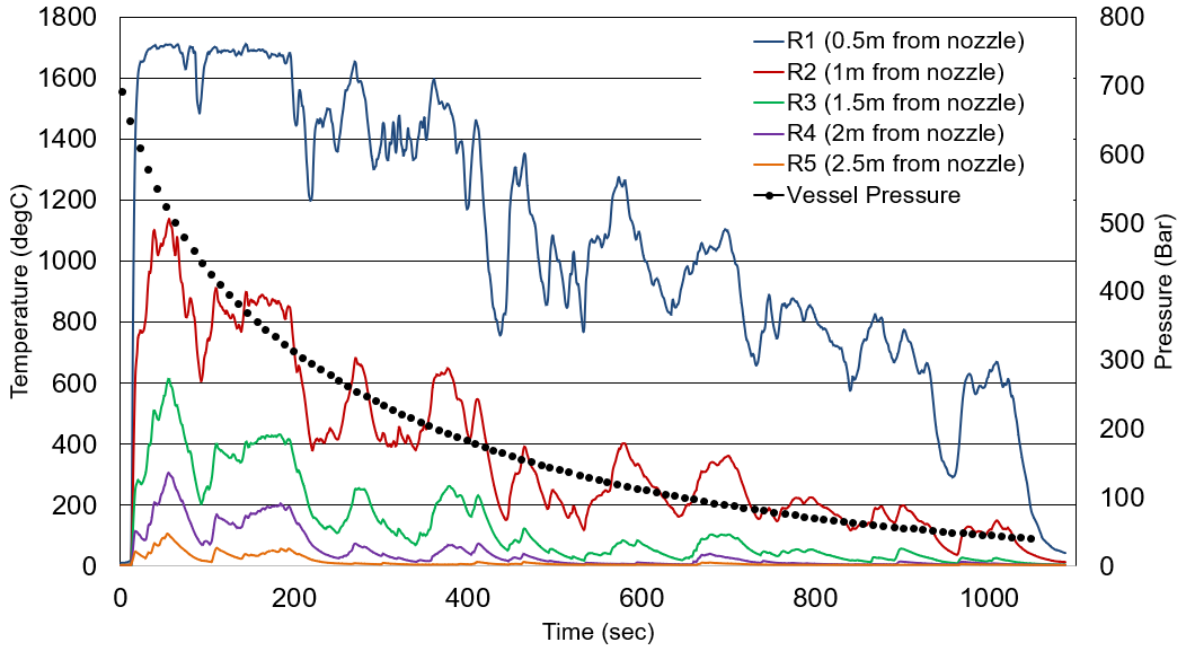



*Figure 8: 700 bar blowdown, 50 L volume, 2 mm nozzle ignited release. Type 'R' thermocouple measurements along the axial direction of the jet*

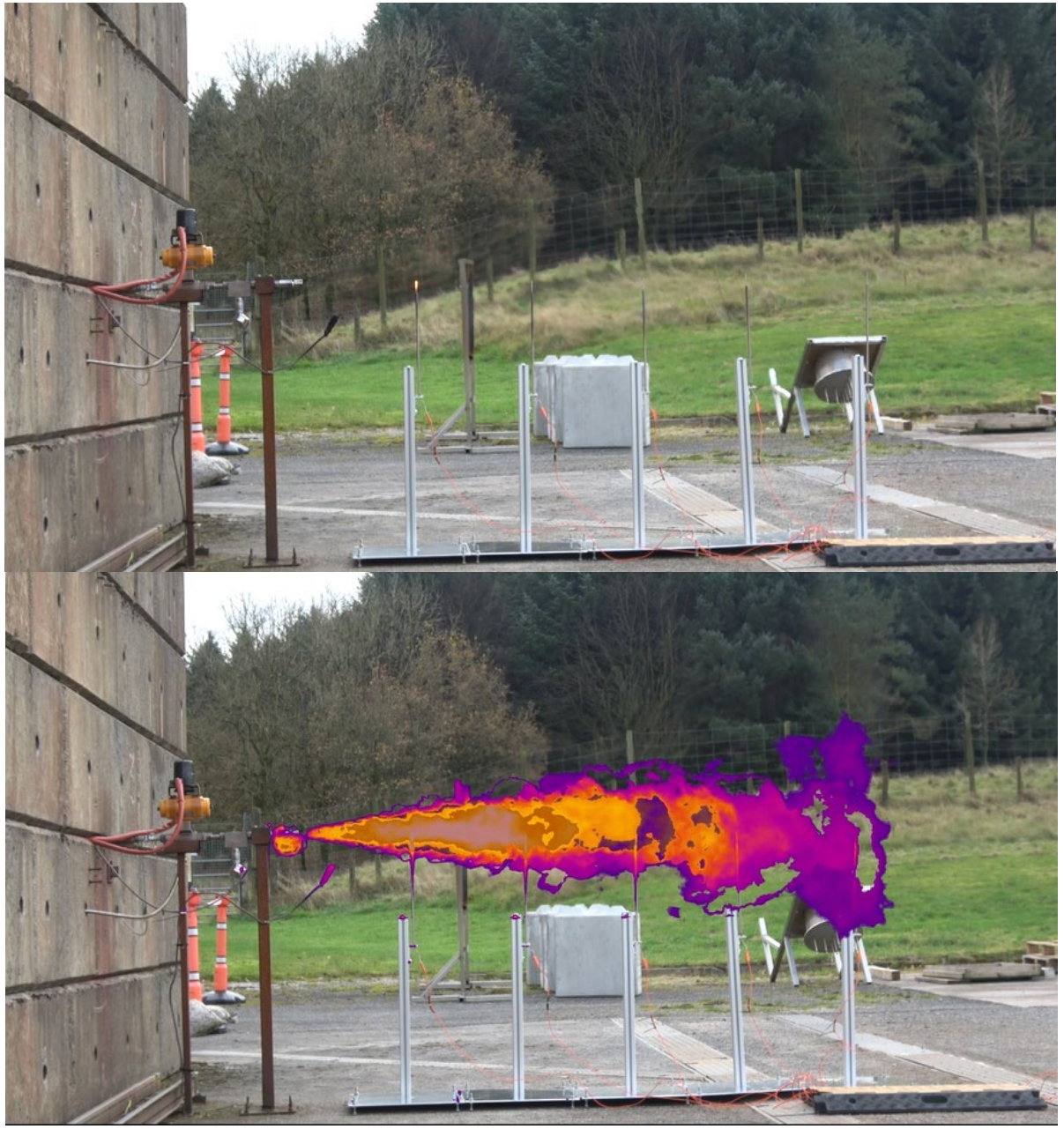
- Temperatures up to 1650°C, up to distances of 3m (likely up to 4m)
- Blowdown for almost 2minutes

# Free jet

## 0.5mm nozzle, 700 bar, 50L




*700 bar blowdown, 50 L volume, 0.5mm nozzle ignited release.*
*Type 'R' thermocouple measurements along the axial direction of the jet*

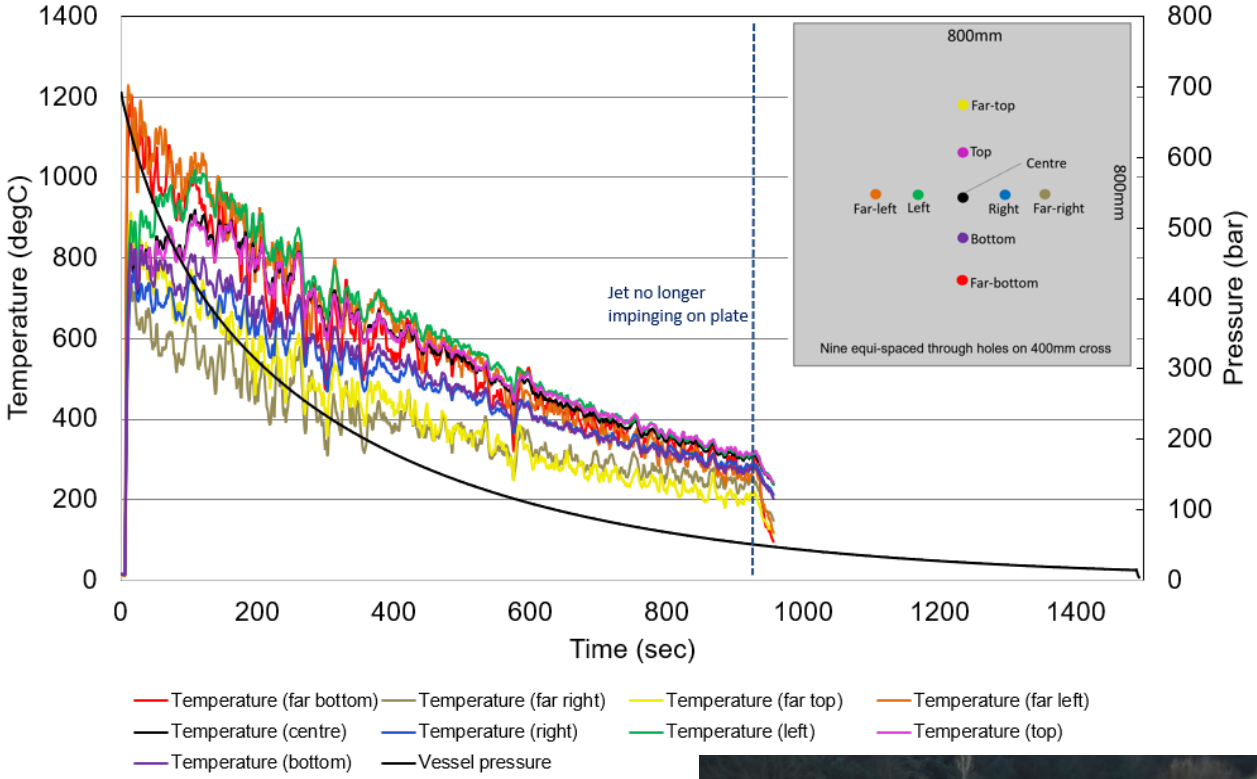


- Temperatures up to 1650°C, up to distances of 0.5m
- Duration over 15minutes

# Impeded jet –sensing plates

## Understanding temperature and pressure impact on concrete samples

- Maximum temperature reached with 2mm nozzle (1400°C on outer TCs)
- Maximum temperature reached with 0.5mm nozzle (1200°C)
- Maximum pressure magnitude with 2mm nozzle 92mbar at centre sensor
- No pressure readings above background with 0.5mm nozzle.



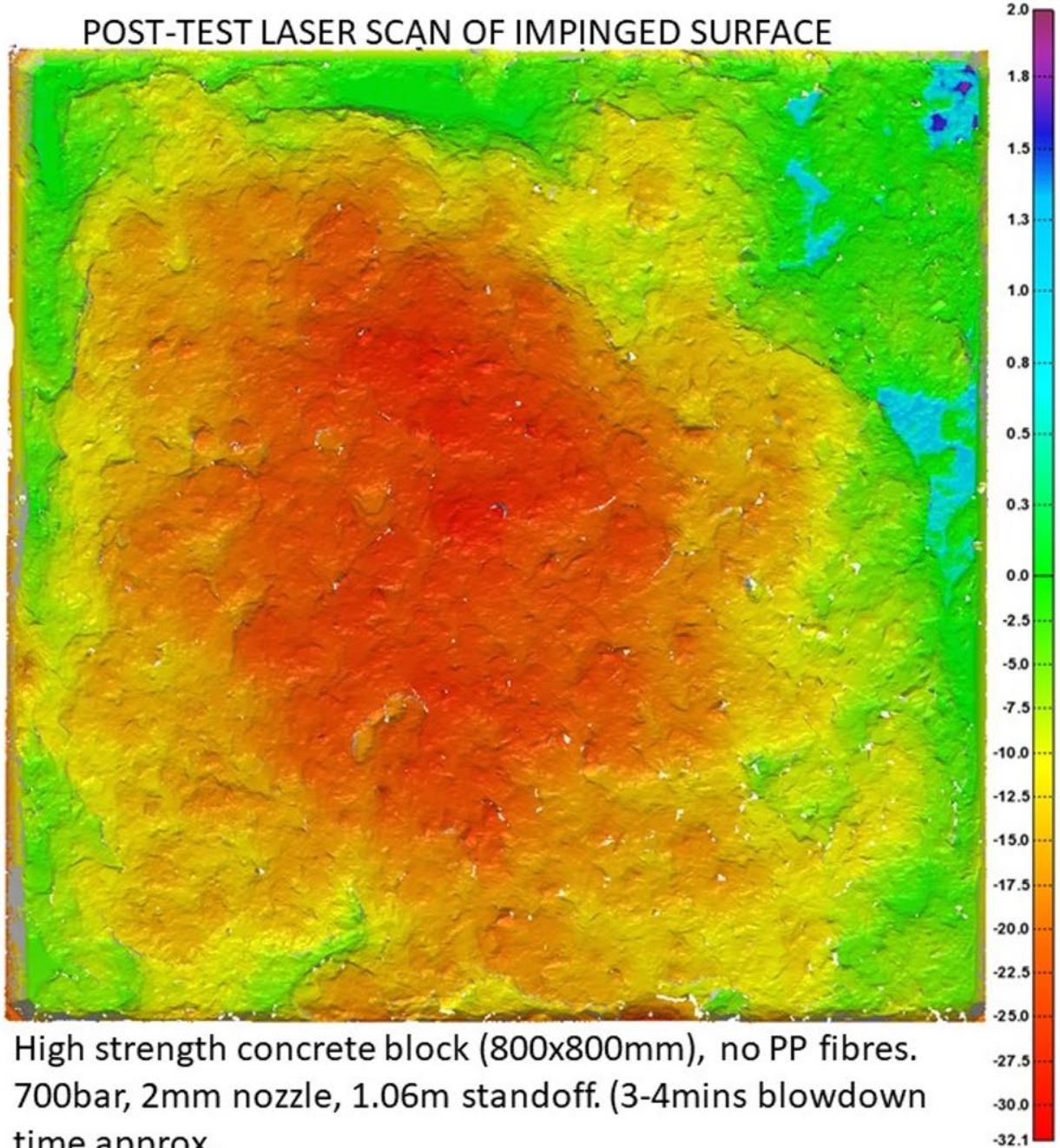

# Impeded jet – Concrete samples

## 700bar, 100L, 2mm nozzle, 3-4mins blowdown approx.

**Test sample – No fibres, 1.06m standoff**

**Test sample – With fibres, 1.06m standoff**

POST-TEST LASER SCAN OF IMPINGED SURFACE




High strength concrete block (800x800mm), no PP fibres. 700bar, 2mm nozzle, 1.06m standoff. (3-4mins blowdown time approx.

POST-TEST VISIBLE IMAGE OF IMPINGED SURFACE

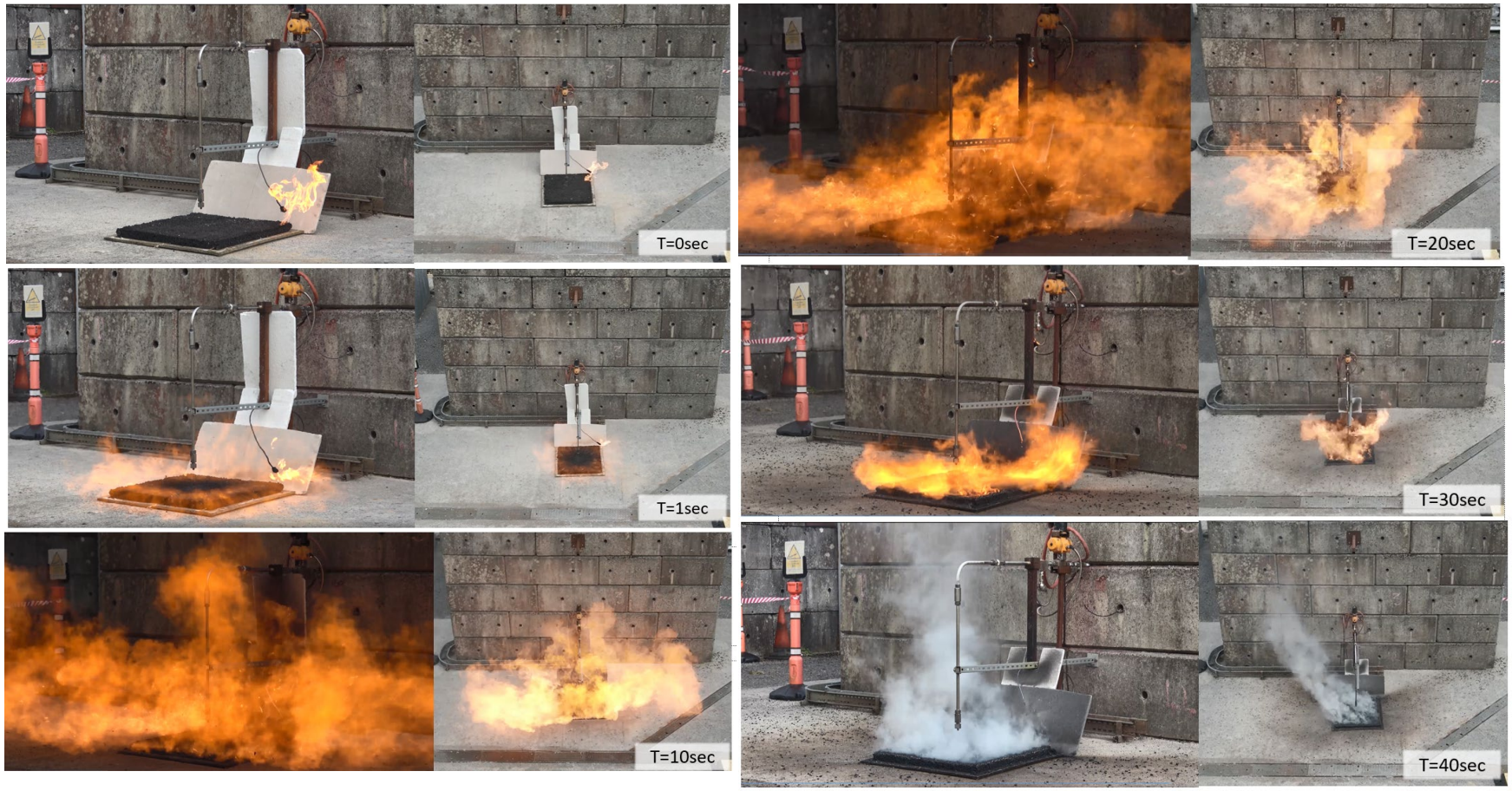
# Concrete analysis

## Post-test analysis – laboratory testing

- Compressive strength – crush test carried out before and after release. 55.3 N/mm$^2$ unimpinged vs 54.9 N/mm$^2$ jet impinged
- Thermal conductivity – Measured to a depth of 45 mm 0.792 unimpinged vs. 0.649 $W \cdot m^{-1} \cdot K^{-1}$ jet impinged. Potential moisture loss reducing the thermal conductivity
- Ultrasonic testing – A pulse velocity measurement to a depth of 190mm was made to investigate presence of cracks or voids, changes in uniformity of the concrete. Velocity measurements from un-impinged and impinged surfaces suggested uniform concrete composition

# Impeded jet - Tarmac samples

## Effect of jet on bituminous material




800x800x40mm, Tarmac

- Expecting a lot of black smoke potentially
- During jet release, appeared that hydrogen was the main fuel burning

# Discussion

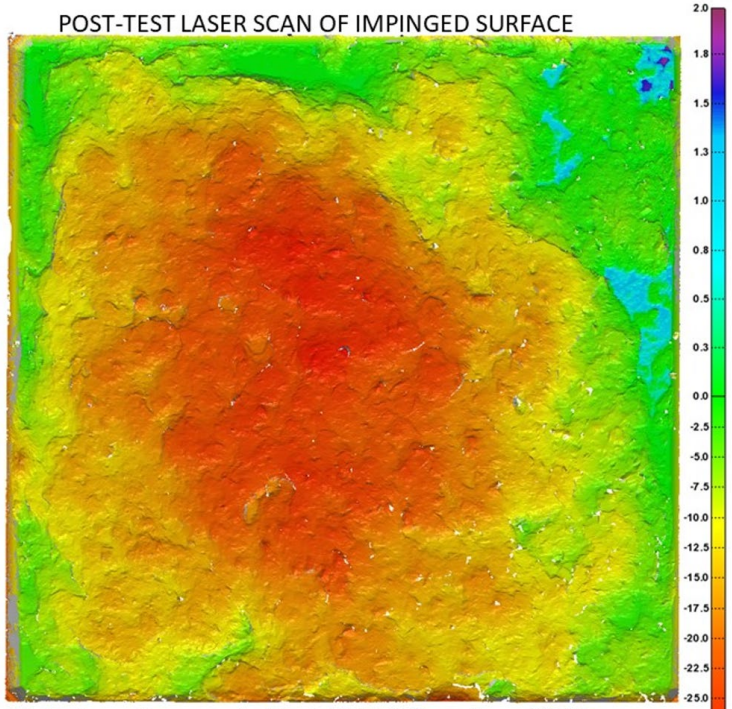
## Considering safety aspects relating to hydrogen jet

Jet release characteristics –

- Temperatures up to 1650°C with good air entrainment, 1400 °C with obstruction*
- Hazard distances reduced if using smaller nozzle i.e. max temperature measured at 0.5m from release point vs. over 3m

Hydrogen jet erosive effects –

- appear to be fairly superficial i.e. within the sacrificial layers considered in tunnel design*
- Polypropylene fibres effective against hydrogen jets



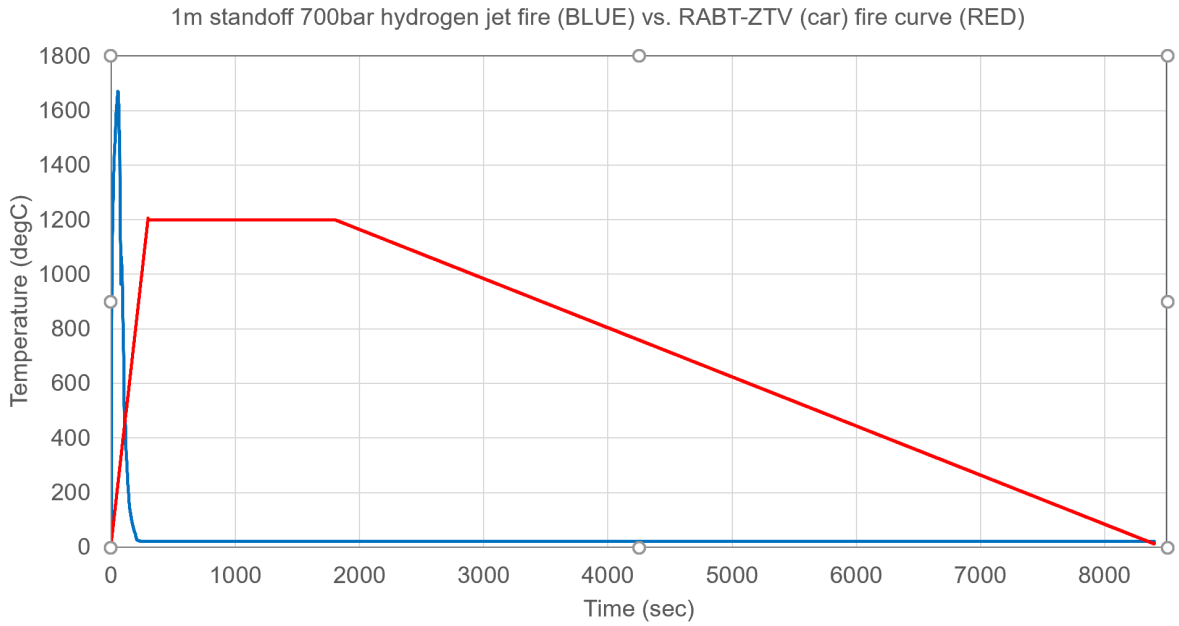

High strength concrete block (800x800mm), no PP fibres. 700bar, 2mm nozzle, 1.06m standoff. (3-4mins blowdown time approx.

*based on these parameters and test method

# Potential contribution to recommendations

## Fire curves to account for hydrogen jet fire

- Hydrogen “fire curve” - short duration but rapid temperature increase (consider other inventory)
- Could possibly use furnace setup rather than high pressure jet as temperature potentially a greater contributory factor than pressure (dependent on time of ignition)



# Potential contribution to recommendations

## Fire safety for first responders

- Hydrogen jet itself not visible however turbulence, poor air entrainment/fuel rich jet portion, interaction with other surfaces gives bright orange flame
- Jet, whether ignited or unignited gives loud “whooshing” noise

**Jet blowdown, 350bar, 3.3m standoff distance, 5mm nozzle. Still of visible recording (5 secs approx. into release)**

# Acknowledgements

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (JU) under grant agreement No 826193. The JU receives support from the European Union's Horizon 2020 research and innovation programme and United Kingdom, Germany, Greece, Denmark, Spain, Italy, Netherlands, Belgium, France, Norway, Switzerland.