Advanced Gas Reactor Fuel and its Behaviour During Drying

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Project Background

Fig 1. AGR fuel assembly [1]

What is the current strategy?:

The current strategy is to interim wet store the fuel pending a decision on final disposal. This is expected to be into a GDF in 2075, with dry storage being investigated as an alternative interim storage method. In addition, drying will be required for disposal. To reduce the risk of corrosion in storage the ponds are dosed to a pH of 11.4 [2].

Why do we need to dry the fuel?

Drying will reduce the risk posed by radiolysis.
If the cladding has failed then water could seep through any cracks during wet storage.
If water is not removed then radiolysis can produce H_2 and H_2O_2.
H_2 is flammable and explosive while H_2O_2 is corrosive and will exacerbate the issue.

Fig 2. Fuel receipt and storage pond [3]

Experimental Work

1. Produce representative cracks in stainless steel.
2. Measure the leak rate through pinhole and crack defects.
3. Conduct drying trials with the pinhole and crack samples.
4. Validate the process model produced to model the drying.

Computational Work

1. Model the flow of gasses through pinholes.
2. Model the flow through a crack network.
3. Characterise the representative cracks produced.
4. Validate this model using the drying trials.

Stress Corrosion Cracking

Thermal conditions and radiation can cause sensitisation of the cladding.
The chromium is depleted around the grain boundaries leaving them susceptible to attack and corrosion.
This leads to narrow tortuous cracks which follow grain boundaries.

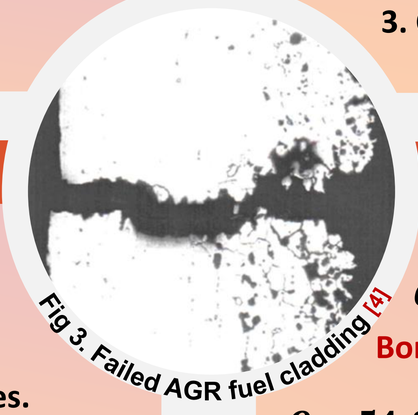

Fig 3. Failed AGR fuel cladding [4]

Comparing Flow Models

Taggart & Budden [6]:

$$Q = C_D \cdot (P \cdot \rho)^{1/2} \cdot W_c \cdot L$$

Bomelburg [7]:

$$Q = 54.8 \cdot m \cdot \frac{d^4}{\mu \cdot l} \cdot (p_u^2 - p_d^2)$$

Beck et al [8]:

$$0 = \frac{\rho \cdot u^2}{2}\left[N\left(1 - \left(\frac{d_{eff}}{d}\right)^2\right)\right] + \frac{2 \cdot u}{\rho}\left[\frac{12 \cdot \mu \cdot l_{eff}}{d_{eff}^2}\right] - \Delta P$$

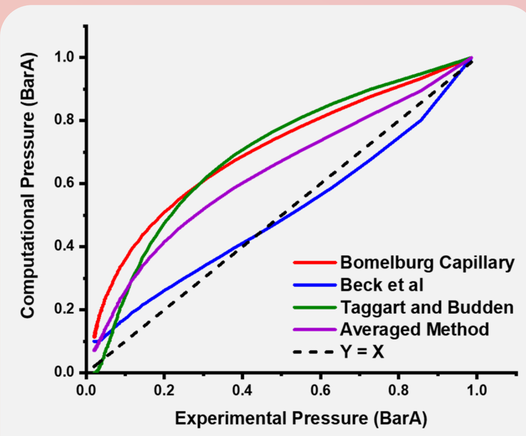

Fig 8. Comparison of the different methods

Producing Cracks

Fig 4. Drop Evaporation (DE) rig in operation

A rig similar to that used for 4 point stress testing of materials and has been used to assess SCC in stainless steels used in offshore oil and gas [5].

The sample is stressed and heated to 180°C.
Then a 35g/L NaCl solution is dripped onto the centre of the sample allowing the previous drip to evaporate before the next droplet falls to concentrate the chloride solution.

Flash Evaporation

Flash evaporation occurs here when the water is suddenly exposed to a reduced pressure.

We are treating it as an adiabatic process with the energy being required for the boiling coming from the water.

$$m_{evap} = \frac{\rho_{water} \cdot V_0 \cdot c_p}{h_{fg}}[T_1 - T_2] \quad [9]$$

$$T_2 = \frac{m_{water} \cdot c_{p_{water}} \cdot T_1 + Q}{(m_{water} - m_{evap}) \cdot c_{p_{water}} + m_{evap} \cdot c_{p_{vapour}}}$$

Drying Trials

Pinholes with diameters: 1µm, 5µm, 20µm, 50µm and 100µm can be used.
The current samples use pinholes however future ones will use cracks produced by the DE rig.

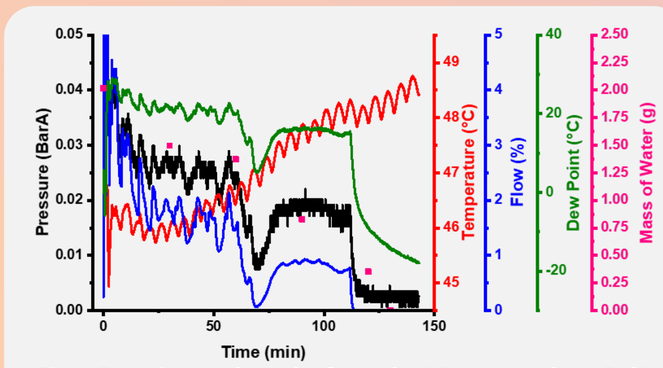

Fig 6. Experimental results from the 20µm sample at 50°C

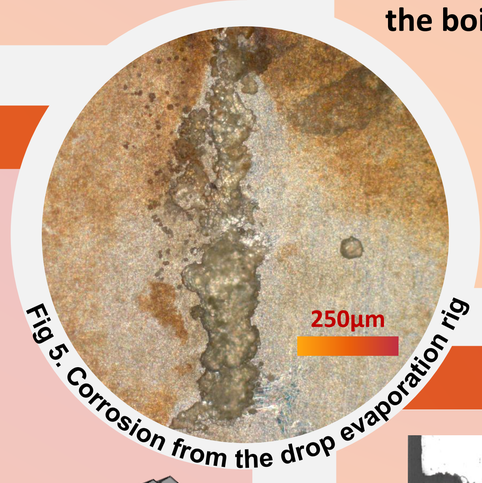

Fig 5. Corrosion from the drop evaporation rig

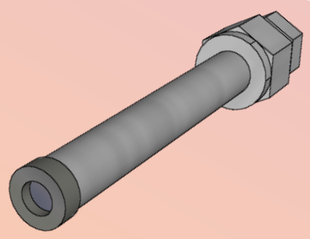

Fig 7. CAD model of the drying sample

Image Analysis

1. Image is cleaned and imported into MATLAB

Fig 9. Binary image of the crack

2. Skeleton is produced and triangles analysed

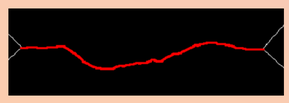

Fig 10. Skeleton of the crack

3. Path length and average width of crack is calculated

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Acknowledgments

Academic Supervisors: Prof. Bruce Hanson, Dr Nicole Hondow
Industrial Supervisor: Dr Carlos de la Fontaine

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