UPISC UNIVERSITY OF PITTSBURGH INFRASTRUCTURE SENSING

COLLABORATION WORKSHOP

NATIONAL ENERGY TECHNOLOGY LABORATORY

Real Time monitoring of corrosion damage-to-crack transitions in Molten Salt Reactors (MSRs)

MSRs are a design of nuclear reactor that utilizes molten salts as fuel/coolant. They are of increasing interest today due to the design benefiting from increases in safety, environmental impact, economic value and non-proliferation[1]. However, the use of molten salts adds to the complexity of corrosion issues, compounding problems from high temperatures and radiation. While maintaining salt composition within careful limits mitigate these concerns[1], this experiment proposes using Fiber optic sensing to capture real time damage to crack transitions in the event of corrosion occurring.

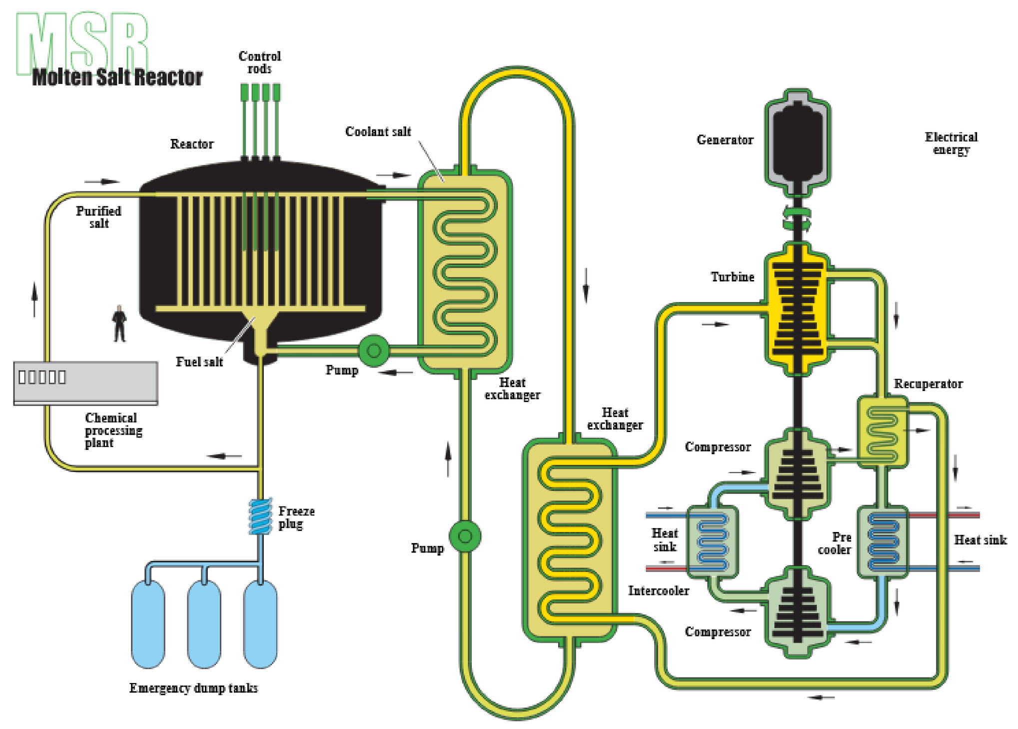

Figure 1 – Overview of an MSR[2]

Experimental Goals:

1. Fundamental understanding of corrosion and cracking behavior for common structural alloys utilized in MSR applications through controlled experimental testing.
2. Characterization of optical fiber and sensor device construction for compatibility with high temperature, harsh environment conditions and acoustic sensing performance.
3. Experimental characterization of acoustic emission events under controlled test conditions with integrated sensors to identify features for corrosion and crack identification
4. Feature identification and/or machine learning model methodology technique development for classification frameworks based on acoustic emission measurement.

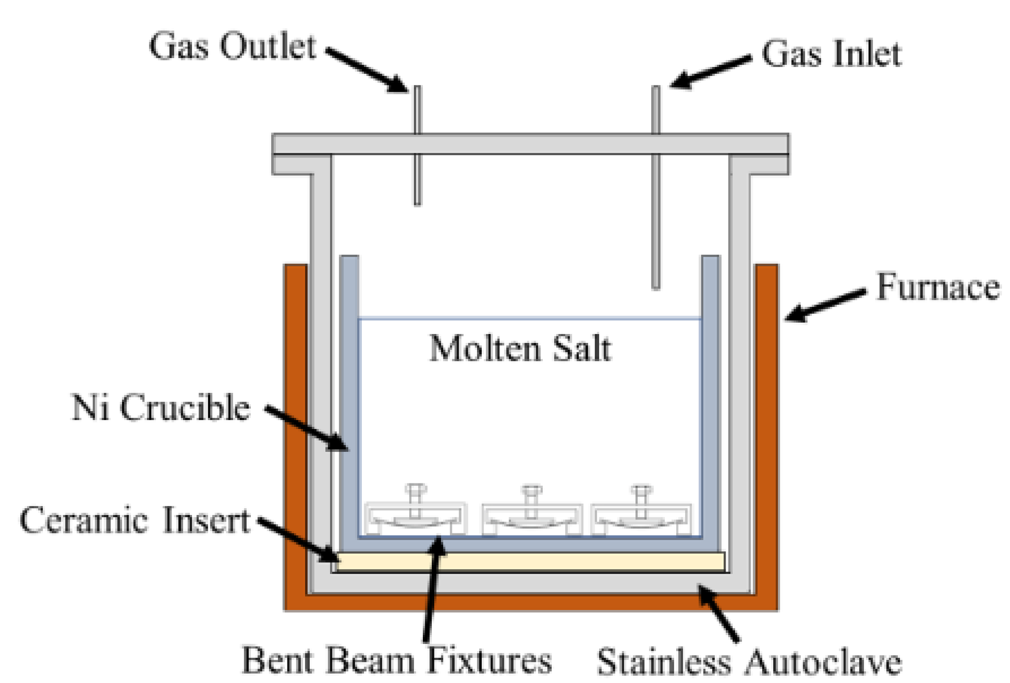

Figure 2 – Schematic of the molten salt test assembly.

Task 1: Development of a Molten Salt SCC Testing Capability

The first requirement for this research is the development of a safe testing system that can SCC metal coupons at 700C. A proposed schematic, adapted from the design used by Chan ete al,[3] can be seen in figure 2. This will include:

- A bolt closed stainless steel autoclave sealed by a stainless steel gasket
- Inert gas inlet/outlet
- Sensing leads

The base stainless-steel structure will be protected from the salts with a disposable Ni Crucible. This setup will be placed in a top load muffle furnace, with a controlled atmosphere of N2. H20 and O2 levels will be maintained below .1ppm via a purifier system.

SCC testing will be executed on Hastelloy N specimens using FLiNaK salts at 700C, using ASTM G39 methodology, due to existing literature for this methods existing as comparison[4]. Samples will be immersed for 240 hours, and then removed and cleaned. After cutting, mounting and polishing, the corrosion attack features will be scanned with an electron microscope and compared to the features shown in prior literature[4].

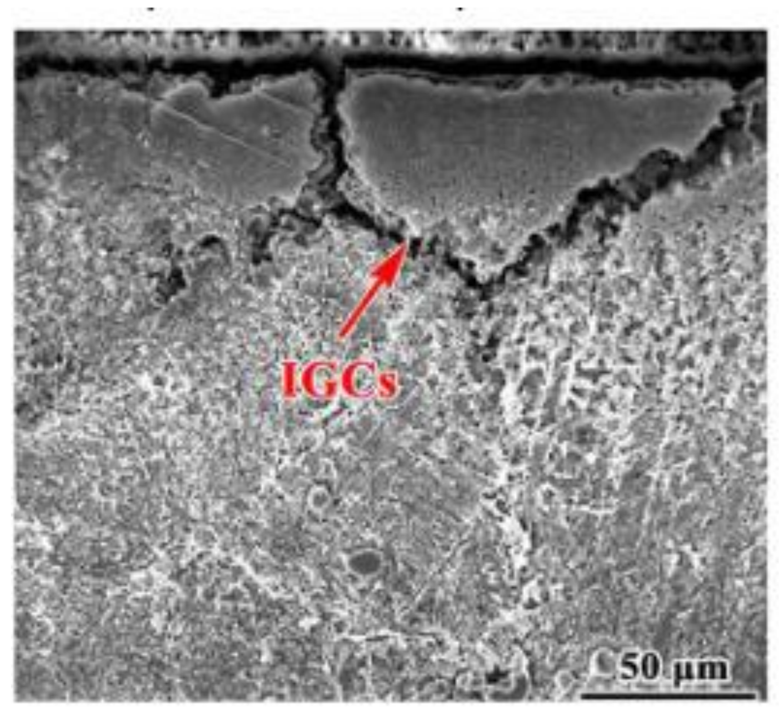

Figure 3 – Representative cross sectional micrograph of near-surface damage observed for Hastelloy-N immersed in FLiNaK salts at 70C for 240 hours[4]

FBG Sensing in MSR conditions

Prior to sensing being done, there are factors that need to be accounted for prior to experiment start:

1. Ensuring the Fiber can survive at these temperatures/survive radiation effects
2. Ensuring radiation/heat effects will not degrade the bonding of the fiber to the metal.

Compatibility with the radiation requirements for the sensors will largely need to be proven through experimentation, however prior work for nuclear applications has shown that pure silica core and F-doped silica clad fibers operate well in said environments. This is on the upper end of the targeted temperature limit, which can leave them embrittleled[5]. For long term applications, the fibers may need to be stabilized to ensure they do not break, or sapphire fibers may need to be used.

For bonding the fiber to the plate, adhesives are the primary focus for keeping the fiber in place. Durabond 952[6] and PELCO high temperature carbon paste[7] both have been used in applications that required adhesion at high temperatures and exhibited radiation affects. These were short term applications though, so further testing needs to be done on their long-term adhesion strength. 3 adhesives from Aremco have, per the manufacturer, some radiation resistance at these temperatures, 516, 835, and 835.

The effects of the adhesive on the wire, and the ability of the wire to withstand MSR conditions will be tested experimentally to ensure that no problems occur The setup will require a wire sensor being placed on a Hastelloy-N coupon, which is then brought to MSR relevant temperatures. If the sensor is able to remain bonded to the metal, and can continue to receive a signal, it will have been considered to have passed this test.

SCC Testing

In addition to the fiber surviving at MSR temperatures, it also needs to be able to detect relevant damage in an in-situ setup. This will involve integrating the wire into the developed MSR SCC testing setup, utilizing at least two condition/material combinations, and applying a tensile load to the material. Success criteria will be for the sensors to be able to capture the onset of crack propagation during an SCC experiment. A proposed approach is offered in figure 5.

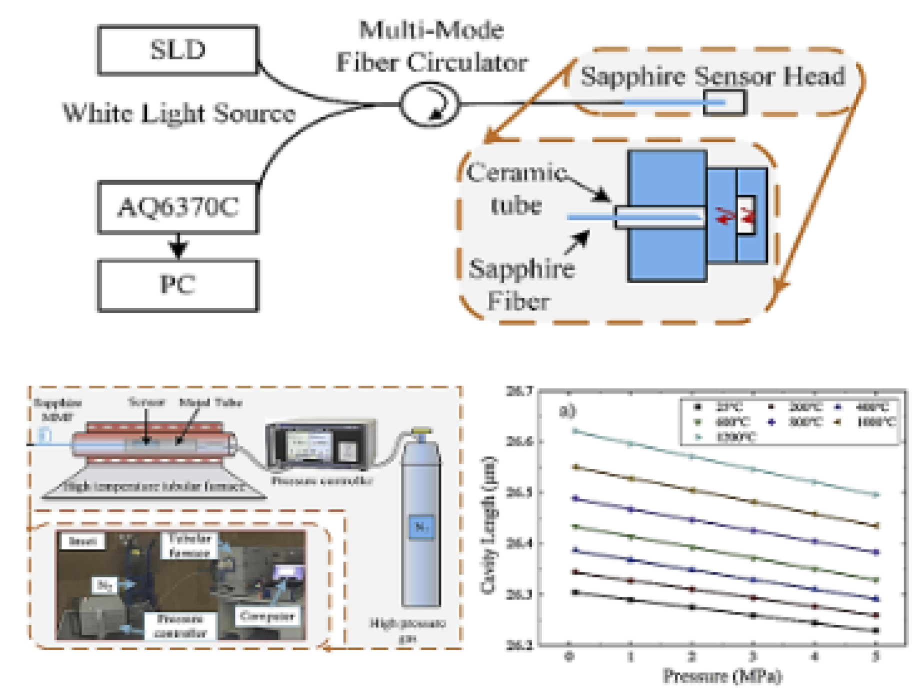

Figure 4 - Example Fabry-Perot interferometric optical fiber sensor device using sapphire fiber successfully deployed in a high temperature, nuclear reactor relevant application showing

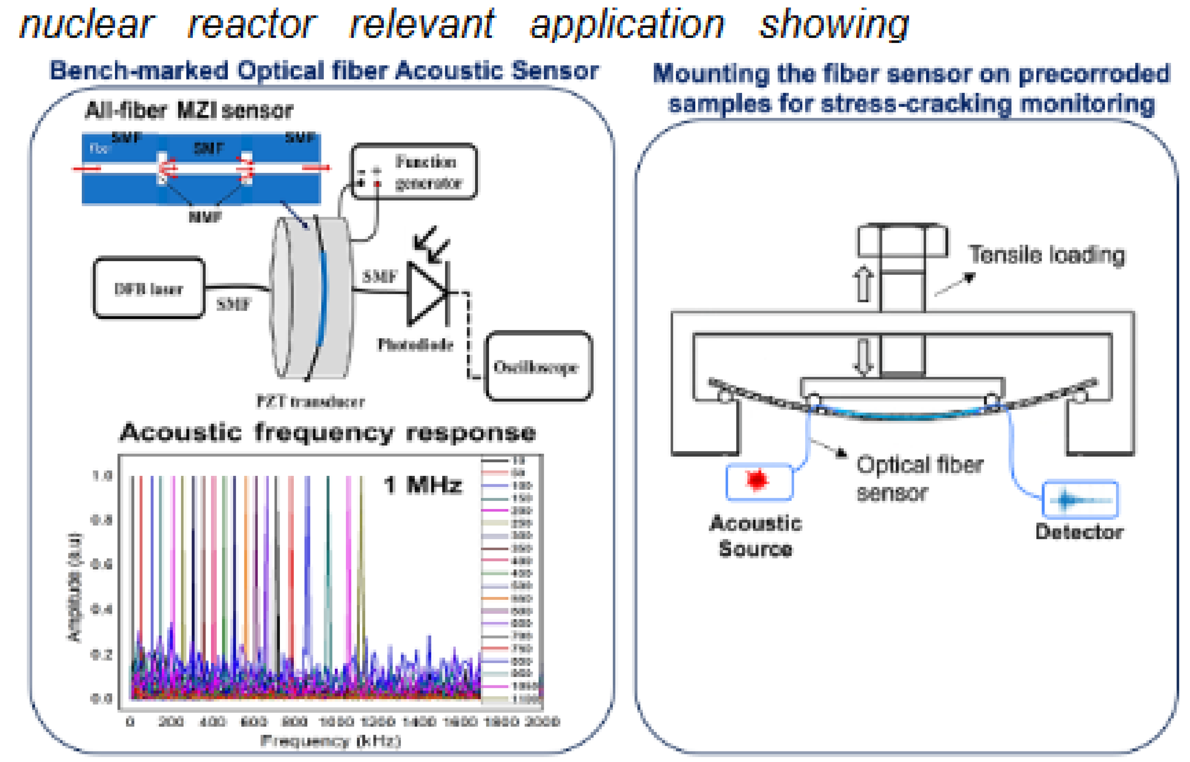

Figure 5 - Multimode interferometric structure based acoustic emission sensing device showing responses at

Citations

[1]IAEA. *Status of Molten Salt Reactor Technology*. International Atomic Energy Agency, 27 Nov. 2023.

[2] *Wikimedia.org*, 2023, upload.wikimedia.org/wikipedia/commons/0/08/Molten_Salt_Reactor.svg.

[3] H.L. Chan, E. Romanovskaia, J. Qiu, P. Hosemann, J.R. Scully, Npj Mater Degrad 6 (2022) 46.

[4] Gu, Yufen, et al. "Stress-Assisted Corrosion Behaviour of Hastelloy N in FLiNaK Molten Salt Environment." *Npj Materials Degradation*, vol. 6, no. 1, 10 Nov. 2022, pp. 1–10, www.nature.com/articles/s41529-022-00300-x, https://doi.org/10.1038/s41529-022-00300-x. Accessed 4 May 2023.

[5] Cook, K, et al. *Technologies for High Temperature Fibre Bragg Grating (FBG) Sensors*.

[6] See Yenn Chong, et al. "Design of Copper/Carbon-Coated Fiber Bragg Grating Acoustic Sensor Net for Integrated Health Monitoring of Nuclear Power Plant." *Nuclear Engineering and Design*, vol. 241, no. 5, 1 May 2011, pp. 1889–1898, https://doi.org/10.1016/j.nucengdes.2011.01.042.

[7] Yu, Fengming, et al. "An Ultrasonic Visualization System Using a Fiber-Optic Bragg Grating Sensor and Its Application to Damage Detection at a Temperature of 1000 °C." *Mechanical Systems and Signal Processing*, vol. 147, Jan. 2021, p. 107140, https://doi.org/10.1016/j.ymssp.2020.107140.