Stress in Microchannel Heat Exchanger Headers

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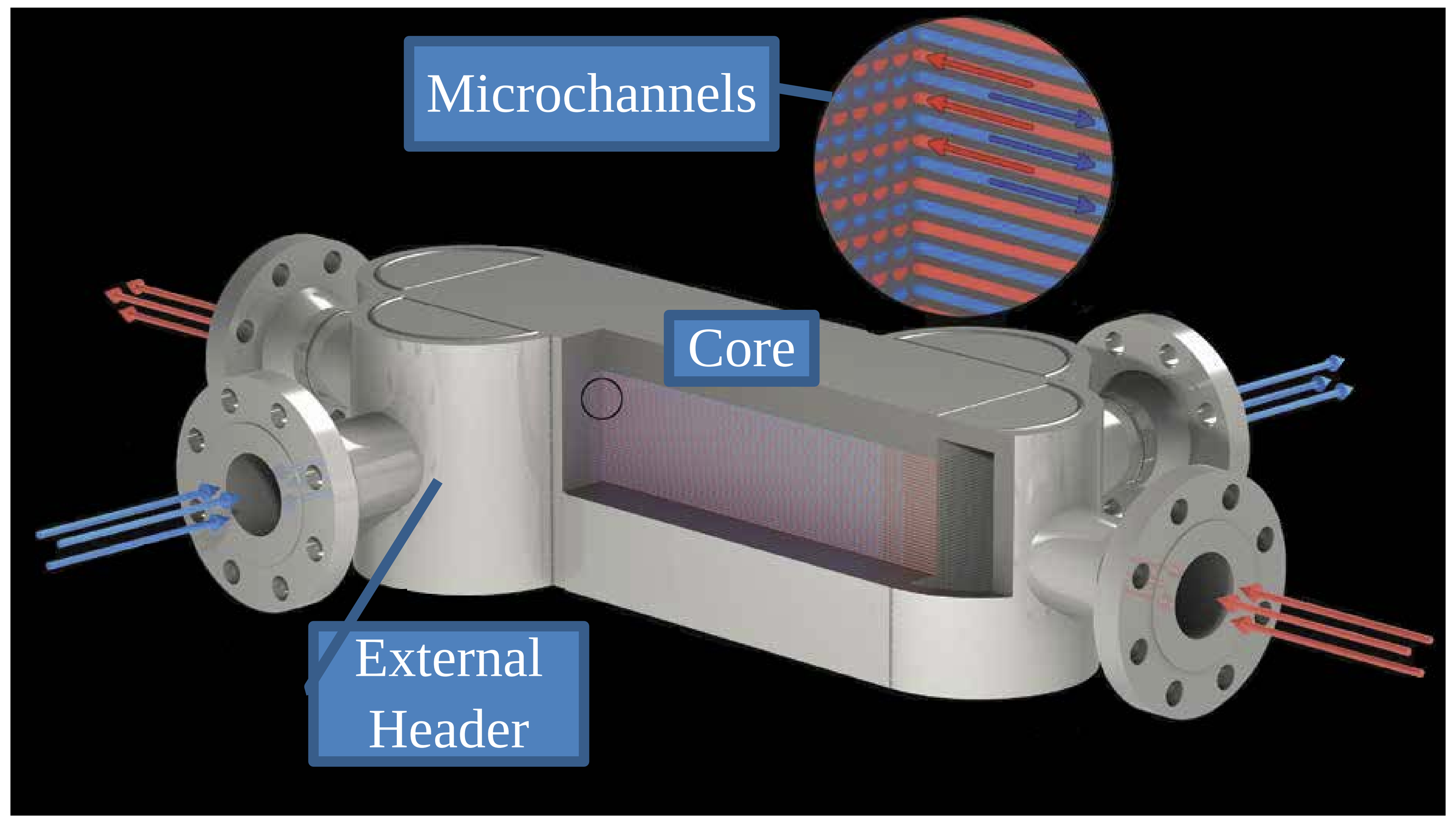
Background

Microchannel Heat Exchanger (MCHE) fatigue life is highly uncertain.

MCHEs are critical components of sCO2 power cycles for their high pressure capability and compactness. But since they are a relatively new technology, there is very little information about failure modes from extreme pressure and fatigue. **Fatigue is a large concern** as the high concentration of solid metal is very stiff and internal stresses are likely to result from fast thermal and pressure transients as well as large temperature gradients. **We seek to understand MCHE behavior under these conditions to retire unknown and potentially significant risks to the power cycle field.**

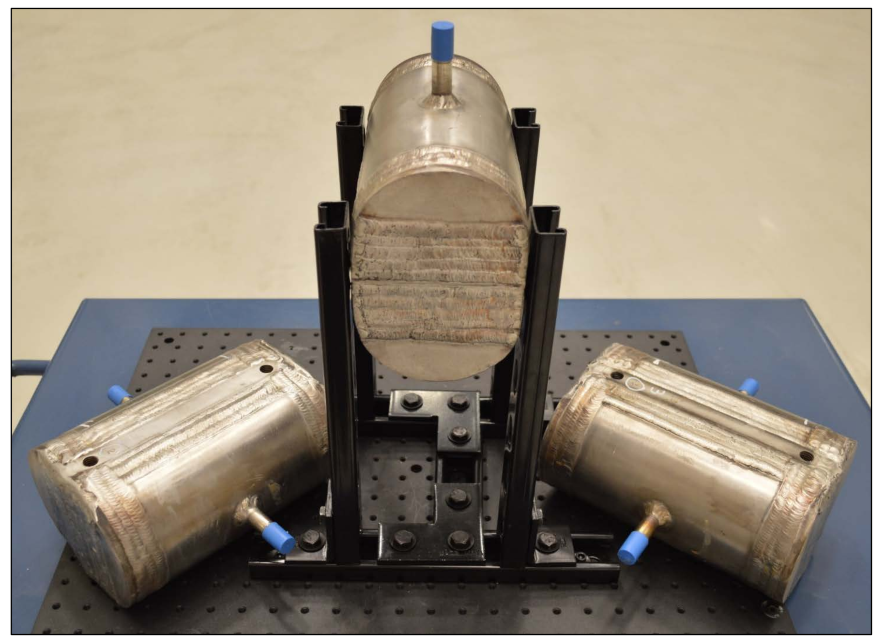


Microchannel heat exchanger configuration with semi-circular headers, [VPE]

Header Prototype Design

Semi-circular header prototypes were designed to ASME BPVC Sec. VIII-1 standards.

Prototypes allow for testing typical header geometries in triplicate without the cost of chemical etching and diffusion bonding of the core. The design rules followed those in Appendix 13-13, Vessels of Circular Cross Section Having a Single Diametral Staying Member. They were made from 316 SS 4 inch schedule 160 pipe. The pressure rating is 3,250 psi.



ASME

Header prototypes built in triplicate for high pressure burst testing

Experiment

The experiment enables high pressure burst and fatigue testing.

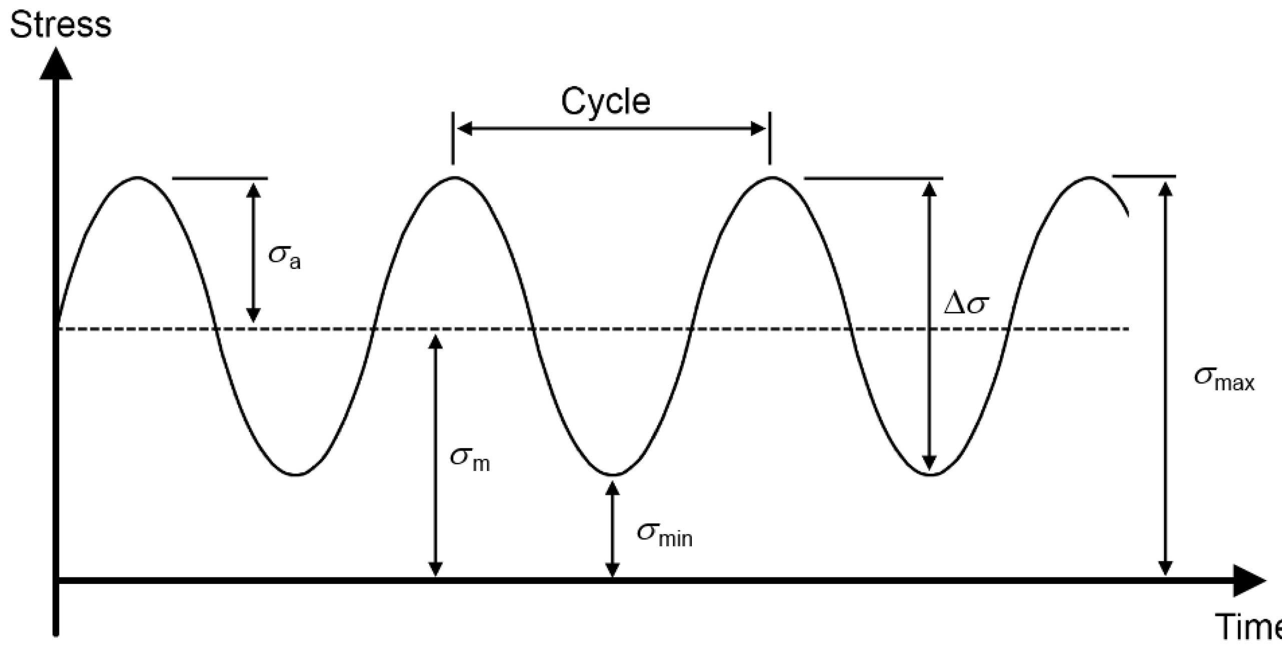
Stress and fatigue failure will be researched with complementary experimentation and simulation. First, header prototypes will be instrumented with strain gauges and pressurized through elastic and plastic strain and finally to failure. The microchannel core has been replaced by a thick plate with drilled holes to restrain motion and reduce costs.

A custom hydrostatic test cart has been acquired for both high pressure burst and low pressure fatigue testing. The experiment has the following features:

- Pressure range from 500-60,000 psi (34 – 4,140 bar)
- Local or remote operation
- Data acquisition and control for 24/7 testing
- Secondary containment for safety

Eventually high temperature CO_2 capability will be added for combined pressure and thermal fatigue experiments. Also Digital Image Correlation (DIC) will be added for full-field strain and deformation measurements.

Pressure Vessel Failure Modes Experiment with hydrostatic pressure cart, data acquisition and control in electrical enclosure, and header prototype inside secondary containment shipping container

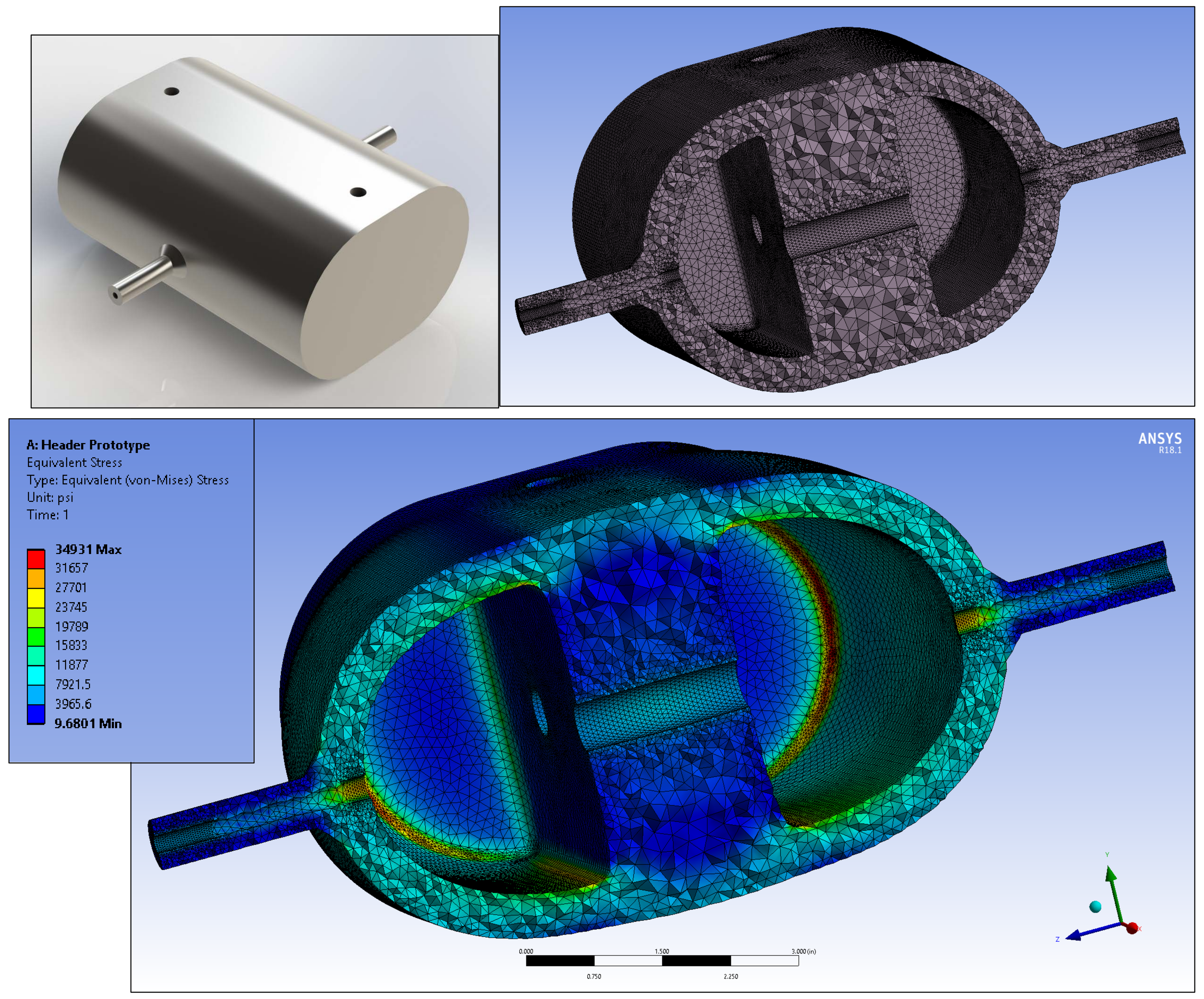


Generalized pressure-induced mechanical fatigue that will be imposed on prototypes [https://www.comsol.com/multiphysics/material-fatigue]

Simulation

Finite Element Analysis (FEA) provides insight into stress and strain distributions.

Stress and strain predictions are performed with FEA in ANSYS Mechanical. The simulation geometry matches the as-built geometry so comparisons between experiments and simulations can be made, providing confidence in simulation results. Once confidence is built in simulations, FEA results can be leveraged to provide high fidelity stress and strain predictions.



Header Prototype solid model (top left), FEA mesh with ~1M elements (top right), and von Mises stress (bottom). Note the stress concentration at the inside corners as expected.

Continuing Work

We plan to run several burst and fatigue tests in the next six months and start HPC simulations.

The three header prototypes will be tested to failure with subsequent examination. Also a fully-operational MCHE will be pressure and thermal fatigued to failure.

Sandia National Labs and Vacuum Process Engineering have recently won a HPC4Mtls award for $300k to simulate the full MCHE geometry with coupled fluid, thermal, and transient stresses to gain greater understanding of expected fatigue life.

HPC4 MATERIALS for Severe Environments

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