U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
SOLAR ENERGY TECHNOLOGIES OFFICE

SETO CSP Program Summit 2019

Progression to Compatibility Evaluations in Flowing Molten Salts

Gen3 CSP Laboratory Call

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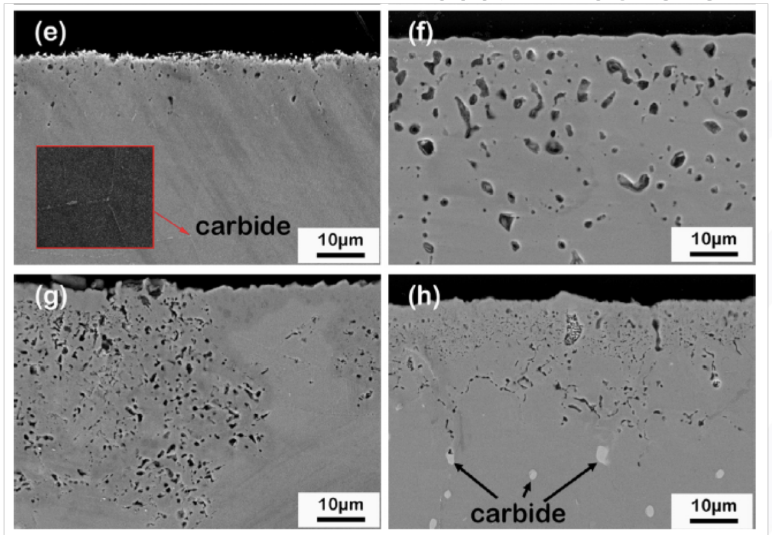
Many literature examples of corrosive chloride salt

Sun 2018: 700°C/100h Na-K-Mg-Cl

C22: Ni-22Cr-13Mo

600: Ni-16Cr-9Fe



625: Ni-22Cr-9Mo

230: Ni-22Cr-13W

Raiman 2018: data analytics

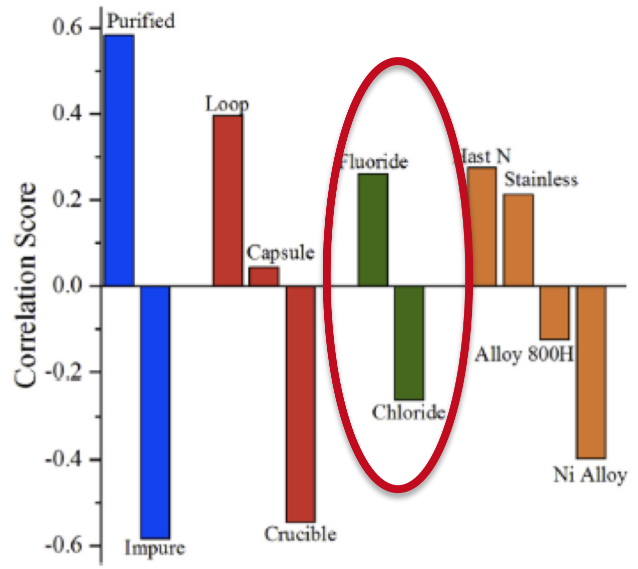
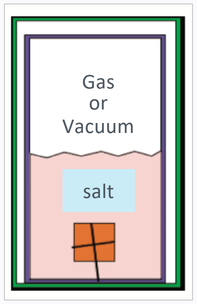


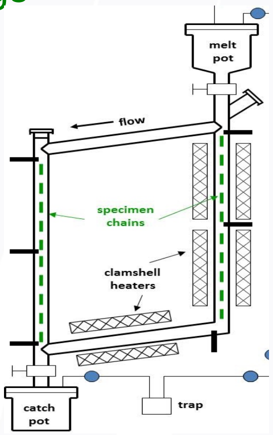
Fig. 8. Correlation analysis result for experimental settings. More positive are correlated with lower corrosion rates, while more negative scores are correlated with higher corrosion rates. The variables depicted are, from left to right: salt purity, experiment type, salt type, and sample material 26.

How do we assess molten salt compatibility?

- Thermodynamics
  - First screening tool but data is not always available
- Capsule
  - Isothermal test, first experimental step
  - **Prefer inert material and welded capsule to prevent impurity ingress**
  - Dissolution rate changes with time: key ratio of liquid/metal surface

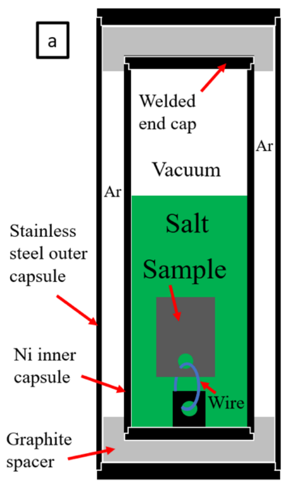


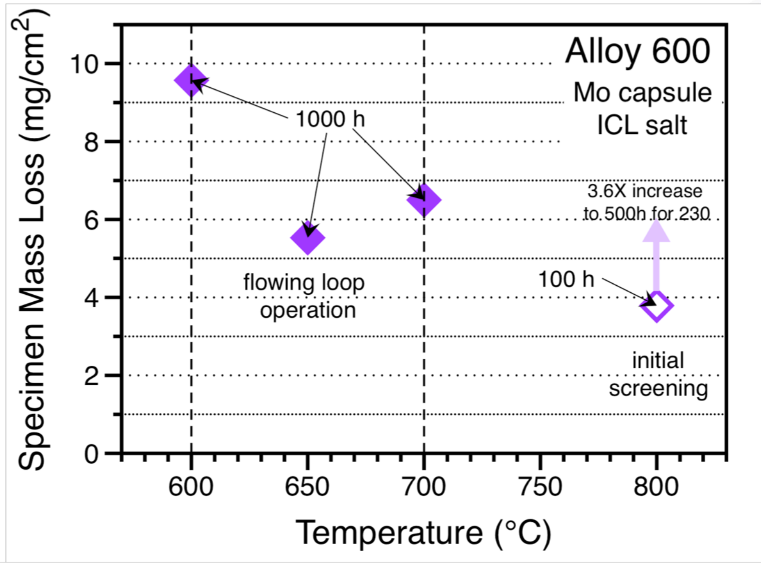
- Thermal convection loop (TCL)
  - Flowing liquid metal by heating one side of "harp" with specimen chain in "legs"
  - Relatively slow flow and ~100°C temperature variation (design dependent)
  - Captures solubility change in liquid: dissolution (hot) and precipitation (cold)
    - Dissimilar material interactions between specimens and loop material
- Pumped loop (FASTR project)
  - Most realistic conditions for flow
  - Historically, similar qualitative results as TCL at 10+X cost



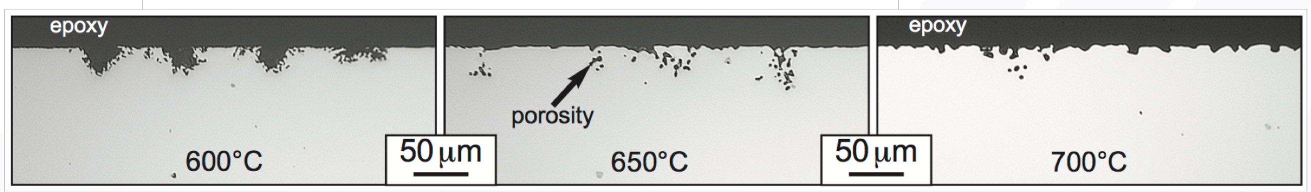
Source: Pawel JNM 2017

Initial thought was salt purification was the cure, but no





- 600: Ni-14%Cr-8%Fe
- Mo capsule
- 1000 h
- Purified commercial K-Mg-Na salt
  - 2 steps: $NH_4Cl + CCl_4$
- High mass losses

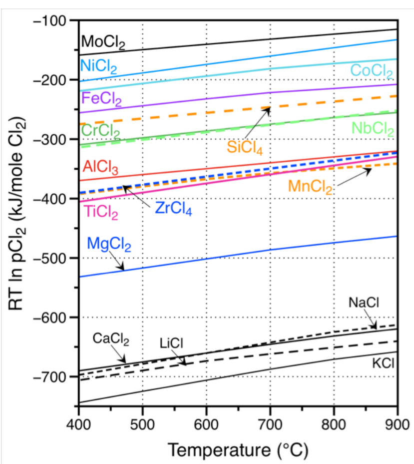


Pit depth: 32±7 µm 16±14 µm 7±5 µm

Thermal convection loop: compromise of parameters

Which salt?

- SETO supplied a commercial K-Mg-Na salt
- What level of O purity?
- **Added 0.04%Mg to lower the Cl potential**



What alloy(s)?

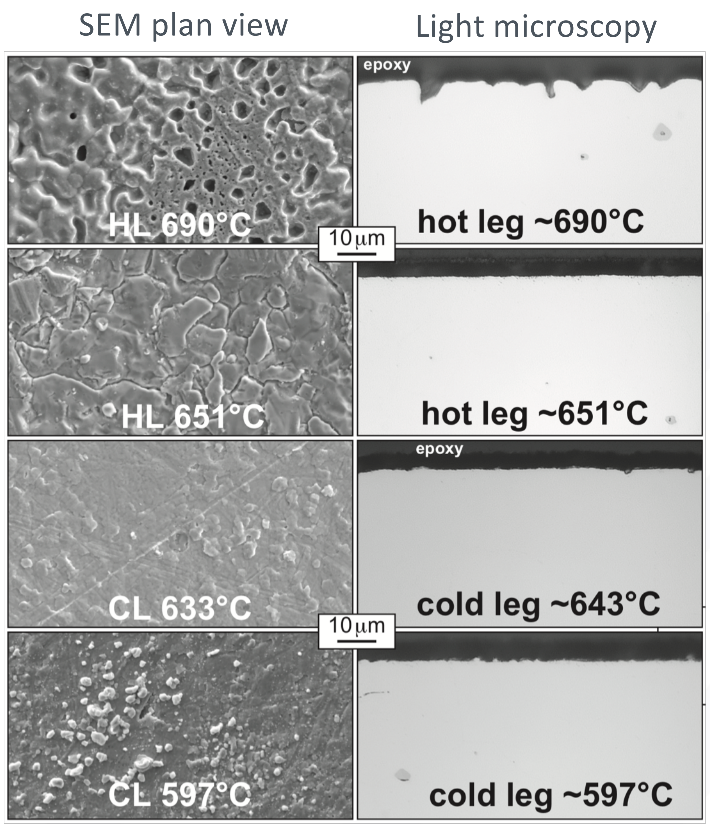
- Must be available in tube, sheet and bar
- Previous experience with **alloy 600**
  - Ni-14Cr-8Fe

Specimen chain

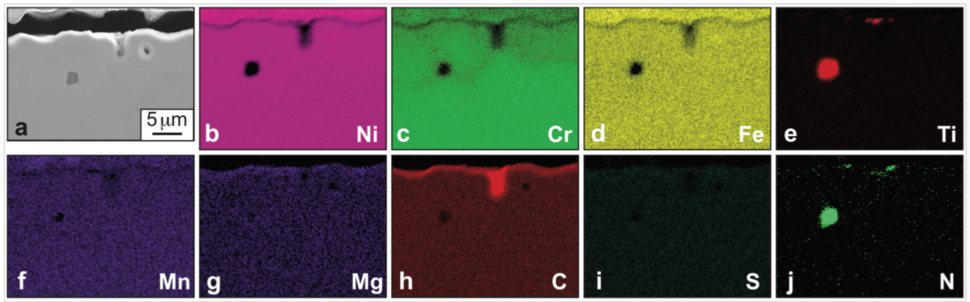
What temperature?

- DOE goal of ~800°C peak temperature
- **Safety: significant risk at 800°C**
- **Compromise: 700°C peak temperature for first loop**
  - **2^{nd} TCL at 750°C**

Specimen morphology consistent with mass change



- Specimen temperatures estimated in hot (HL) and cold legs (CL)
- Porous surface at highest temperature
  - Minimal Cr depletion (10-11% at surface)
- Precipitates on surface at lowest temperature
- Minimal changes observed in between
- Minimal Mg uptake in hot and cold leg

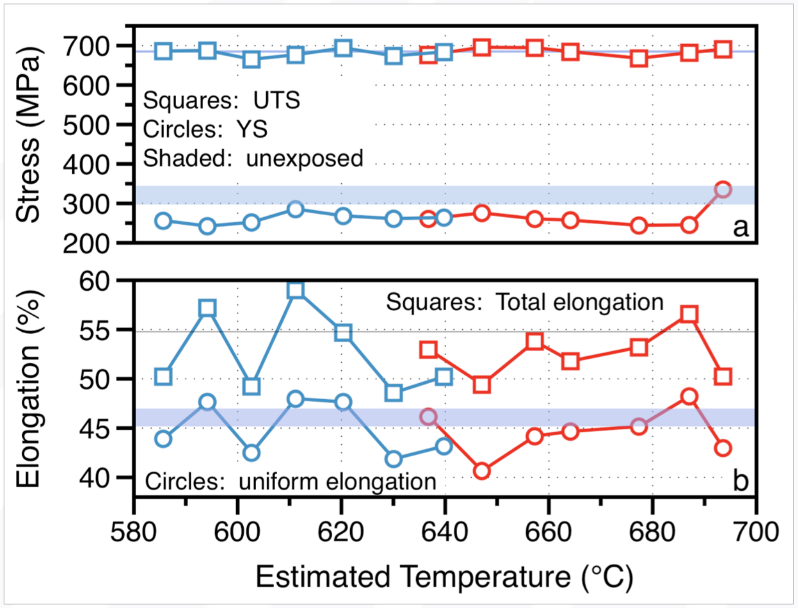


Classic mass transfer behavior

Alloy 600: Little change in 25°C tensile properties

- Half of specimens broken
- Room temperature
- Strain rate 10^{-3} s^{-1}
- Unexposed: blue shaded range
- 1000 h exposures in quartz ampoules at 600, 650, 700°C
  - Separate temperature effect
  - Tests in progress

CL: blue HL: red

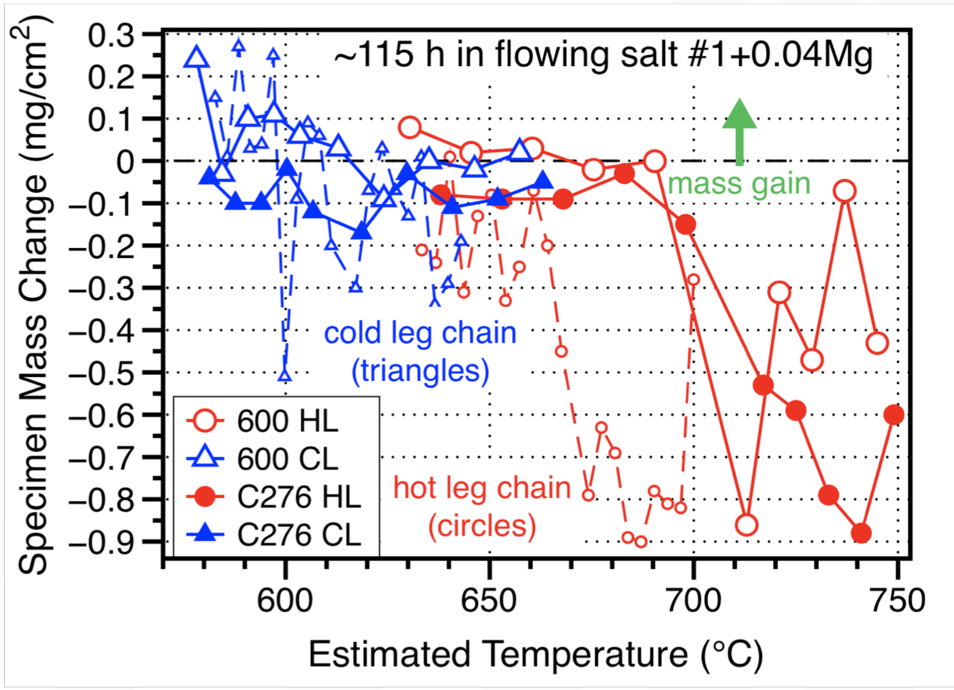


Shaded areas: range of as-rec. properties

Summary: progress in showing Cl salt compatibility

- Promising results suggest that there are Ni-Cr alloys compatible with commercial K-Mg-Na chloride salts at 700°C
  - First flowing salt results showed low mass changes at 580°-700°C
  - Purified commercial salt with 0.04%Mg addition used in two thermal convection loops
- Salt compatibility paradigm from 1950's:
  - Flowing salt experiments are needed with temperature gradient
    - Change in solubility avoids saturation in capsule experiment
  - Fluoride salts were always purified
- **Many unanswered questions remain about the need for purification and optimal Mg additions**
  - Next experiments planned with no purification and Mg additions

Backup slide



2[nd] loop had 600 and C276 specimens and failed after 115h