Effects of Oxygen Partial Pressure on the Surface Tension of Liquid Aerospace Alloys

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Motivation for Thermophysical Properties

- Need high quality thermophysical properties of high-temperature materials.
- These properties are critical for developing accurate models with predictive capability
  - Casting
  - Welding
  - Additive Manufacturing
- Measurements will improve manufacturing of propulsion components, leading to higher performance and higher reliability.

Reference:
http://www.technalysis.com/casting_software.aspx
Need for Oxygen Partial Pressure Control

• Surface tension of molten metals is affected by even a small amount of adsorption of oxygen
  – Oxidation may have an impact of 10-30% on surface tension measurements\(^1\).
  – Causes a decrease in surface tension

• Oxidation can occur at very low \(pO_2\)
  – Has been observed in the MSFC ESL as low as \(\sim 1 \times 10^{-25} \text{ bar } pO_2\)

References:
Supports Microgravity

- This system supports microgravity principal investigators:
  - A similar oxygen control system is planned for the European Space Agency (ESA) International Space Station Electromagnetic Levitator (ISS – EML).
  - Japan Aerospace Exploration Agency (JAXA) Electrostatic Levitation Furnace (ELF) that is planned to fly on the ISS.

Schematic of the JAXA ELF electrode assembly.

Sample inside of the ESA ISS-EML.
Hardware at MSFC

Oxygen Pump inside the levitation chamber.

Oxygen Sensor inside the levitation chamber.

Stand-alone controller.
The system can also be controlled via computer software.

- Developed by Astrium North America
- Fabricated by Clausthal University of Technology (TU Clausthal)
Oxygen Sensing

• **Potentiometric sensor**
  – Determines the difference in oxygen activity in 2 gas compartments separated by an electrolyte
    • Yttria-stabilized zirconia (YSZ)

• **Activity of gaseous compounds corresponds closely with their partial pressures**

• **The cell generates an electromotive force**
  – Difference in pO2 between the process gas and air, which is the reference gas

• **pO2 is calculated by using the Nernst equation**
  – \[ E = \frac{RT}{4F} \ln \left( \frac{pO2}{pO2_{ref}} \right) \]
  – E is the electromotive force
  – R is the universal gas constant
  – F is the Faraday constant
  – \((pO2)_{ref}\) is the oxygen partial pressure of the reference gas (the lab atmosphere, in this case)
  – pO2 is the oxygen partial pressure of the gas in question

Oxygen Pumping

- Electric current is applied to the electrodes (Pt)
  - Charge moved across the electrolyte in the form of oxygen ions, O^{2-}.

- Negative electrode
  - Oxygen is incorporated into vacancies of the electrolyte, $V_{\theta}^{0}$.

- Positive electrode
  - Oxygen leaves crystal lattice to form gaseous oxygen.

- Must be operated above 500°C to enable sufficient ionic conductivity.

Schematic of oxygen ion pump:
Oxygen molecules move through the YSZ tube from inside to outside when a difference in electrical potential is provided between the tube walls.

Test Matrix

- **Inconel 718**
  - Samples were made from rod stock
    - Cut into small wafers by diamond saw
    - Arc melted into spheroids
  - Samples were cleaned with ethanol
- **Sample processing only occurred after the oxygen partial pressure reached equilibrium.**
- **Melting caused the OPPC to change, but the OPPC eventually equilibrated**
  - Surface tension measurements were taken while the OPPC was changing and after equilibrated

- **Oxygen partial pressures studied**
  - $10^{-12}$
  - $10^{-18}$

- **Surface tension measurements were made between 25°C above the melt point down to 30°C below the melt point, including at the melt point**
Example OPPC Plot

Oxygen partial pressure control over time. Set to $10^{-18}$ bar.

Zoomed into the sample heating region.
Surface Tension vs. Temp
Conclusions and Future Work

• Preliminary results do not show a dependence on oxygen partial pressure.

• It is hypothesized that either there is no oxygen on the surface or that the oxygen partial pressure was not high enough to show a dependence.
  – Measurements at higher oxygen partial pressures are planned.
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