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

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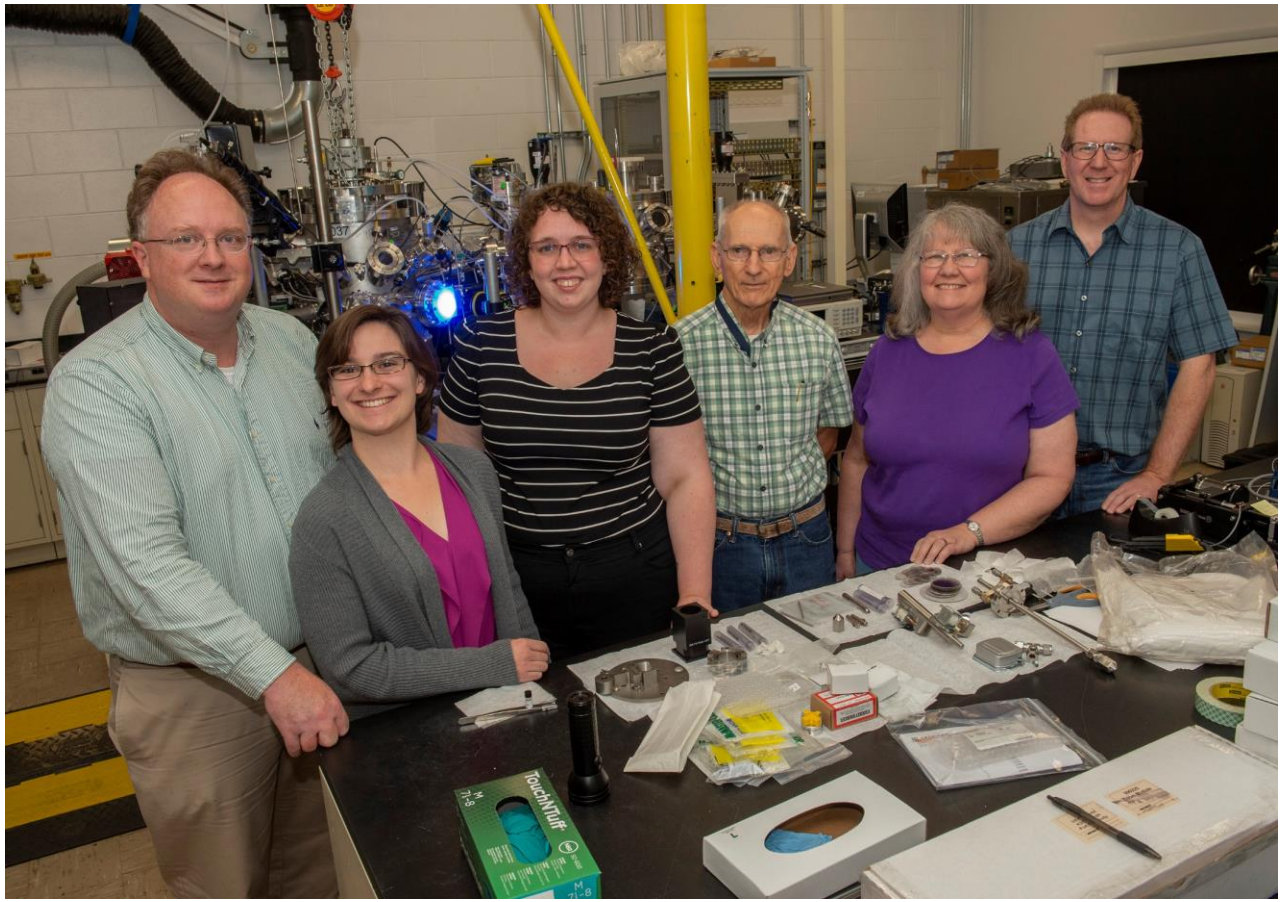
The Team



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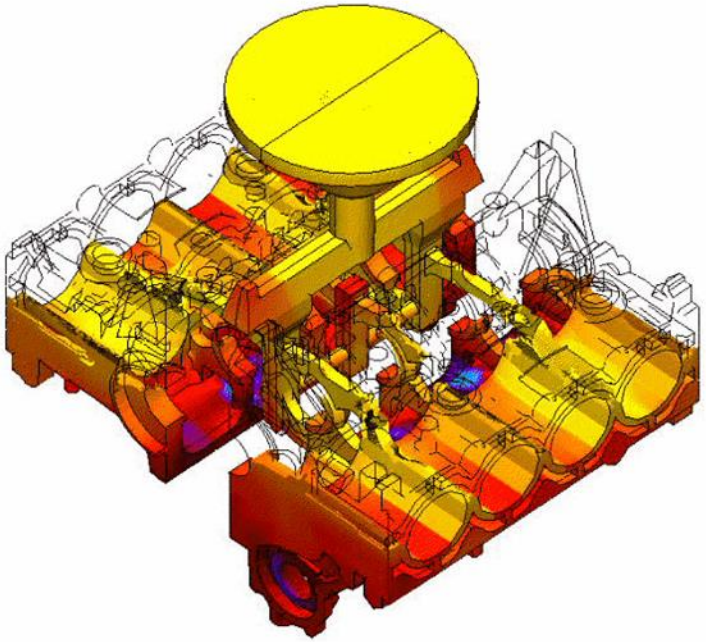
Motivation for Thermophysical Properties

- **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.**



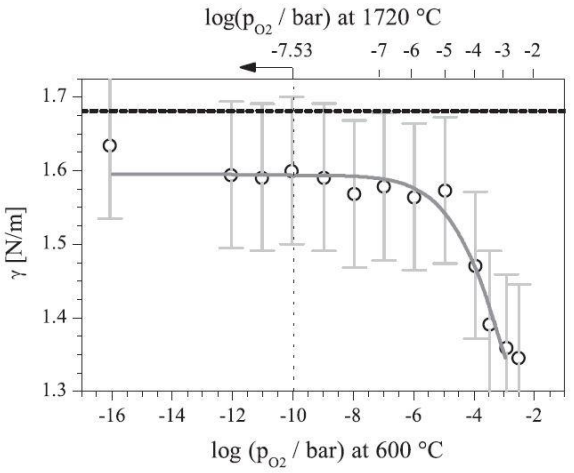
A model of a casting process.

Reference: http://www.technalysis.com/casting_software.aspx

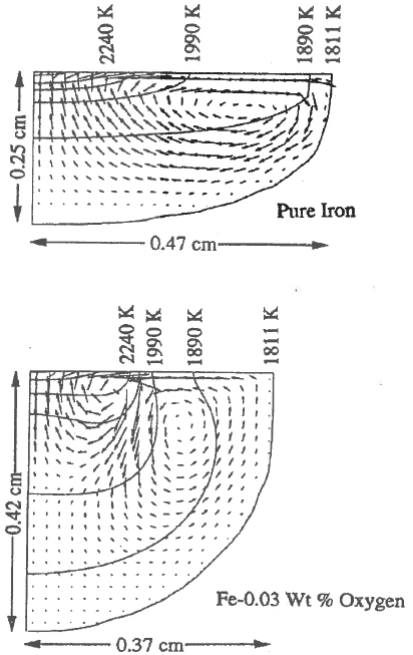
Need for Oxygen Partial Pressure Control

- **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 ~ $1x10^{-25}$ bar pO_2**



The surface tension γ of 99.999% Ni as a function of pO_2 measured by Schulz et. al[2].



Calculated velocity and temperature fields for gas tungsten arc welding of pure iron and iron with 0.03 wt% oxygen[2].

References:

1. Ozawa, S., et. al., Influence of oxygen partial pressure on surface tension and its temperature coefficient of molten iron, Journal of Applied Physics, 2011, 109.
2. Schulz, M., et. al., Oxygen partial pressure control for microgravity experiments, Soliid State Ionics, 225, 2012, p. 332-336.
3. DebRoy, T. and S.A. David, *Physical processes in fusion welding,* Reviews of Modern Physics, 1995, 67(1), p. 85-112

Supports Microgravity

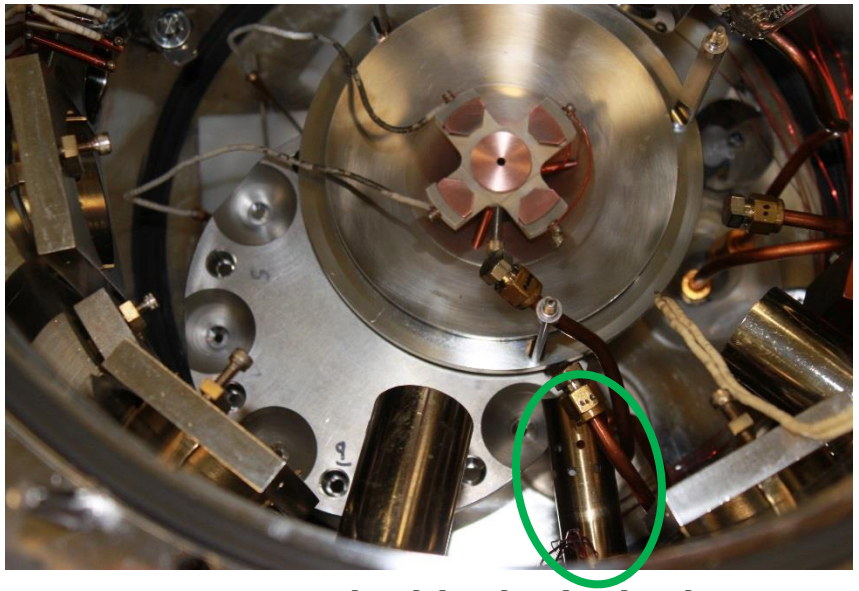
- **This system supports microgravity principal investigators:**
  - **A similar oxygen control system is planned for the European Space Agency (ESA) International Space Station Electromagnetic Levitator (ISS – EML).**
  - **Japan Aerospace Exploration Agency (JAXA) Electrostatic Levitation Furnace (ELF)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

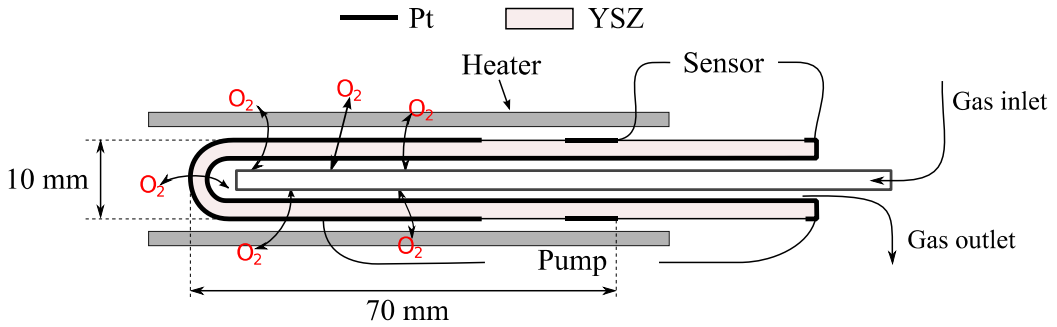
Stand-alone controller.

The system can also be controlled via computer software.

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

Oxygen Sensing

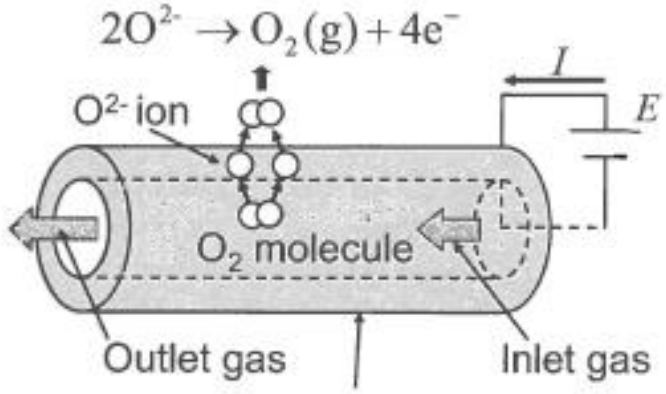
- **Potentiometric sensor**
  - Determines the difference in oxygen activity in 2 gas compartments separated by an electrolyte
    - Yttria-stabilized zirconia (YSZ)
- **Activity of gaseous compounds corresponds closely with their partial pressures**
- **The cell generates an electromotive force**
  - Difference in pO2 between the process gas and air, which is the reference gas
- **pO2 is calculated by using the Nernst equation**
  - E = RT / 4F ln [(pO2) / (pO2)^ref]
  - 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



Schematic of the oxygen sensor. Ref: Schulz, M., et al., *Oxygen partial pressure control for microgravity experiments,* Solid State Ionics, 2012, 225, p. 332-336.

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_O^{00}**
- **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

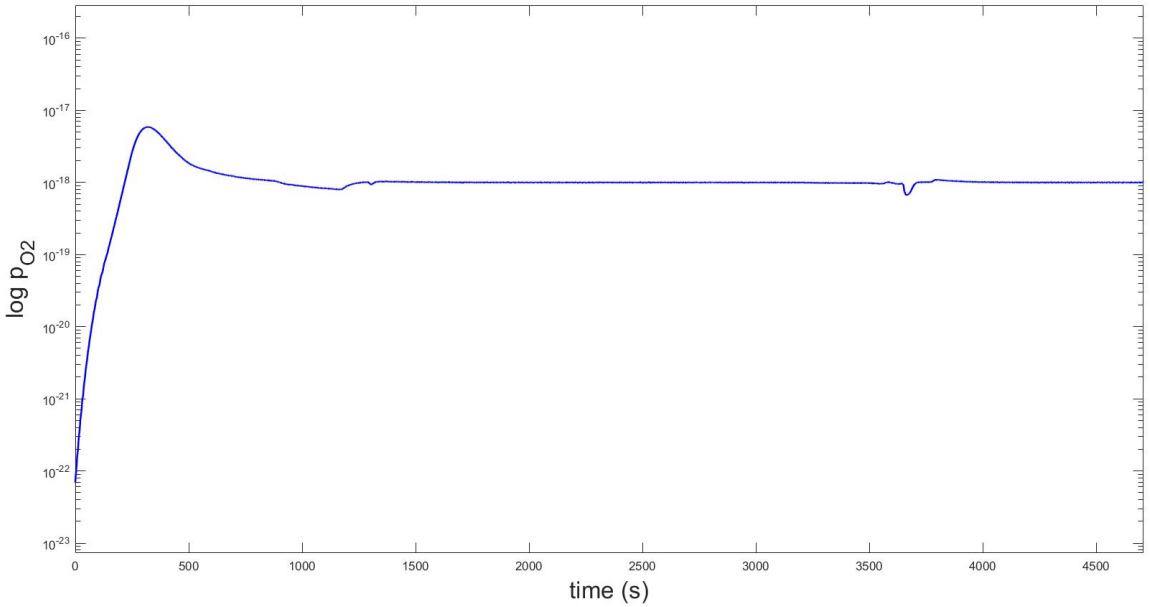
Oxygen molecules move through the YSZ tube from inside to outside when a difference in electrical potential is provided between the tube walls.

Ref: Ozawa, S., et al., Influence of oxygen partial pressure on surface tension of molten silver, Journal of Applied Physics, 2010, 107.

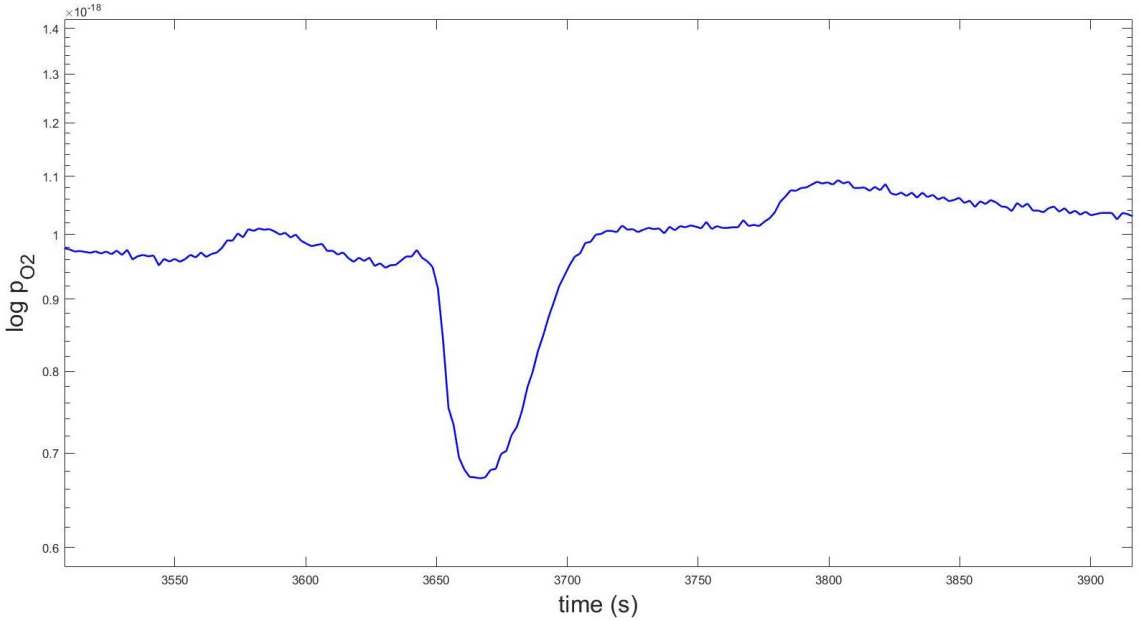
Test Matrix

- 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

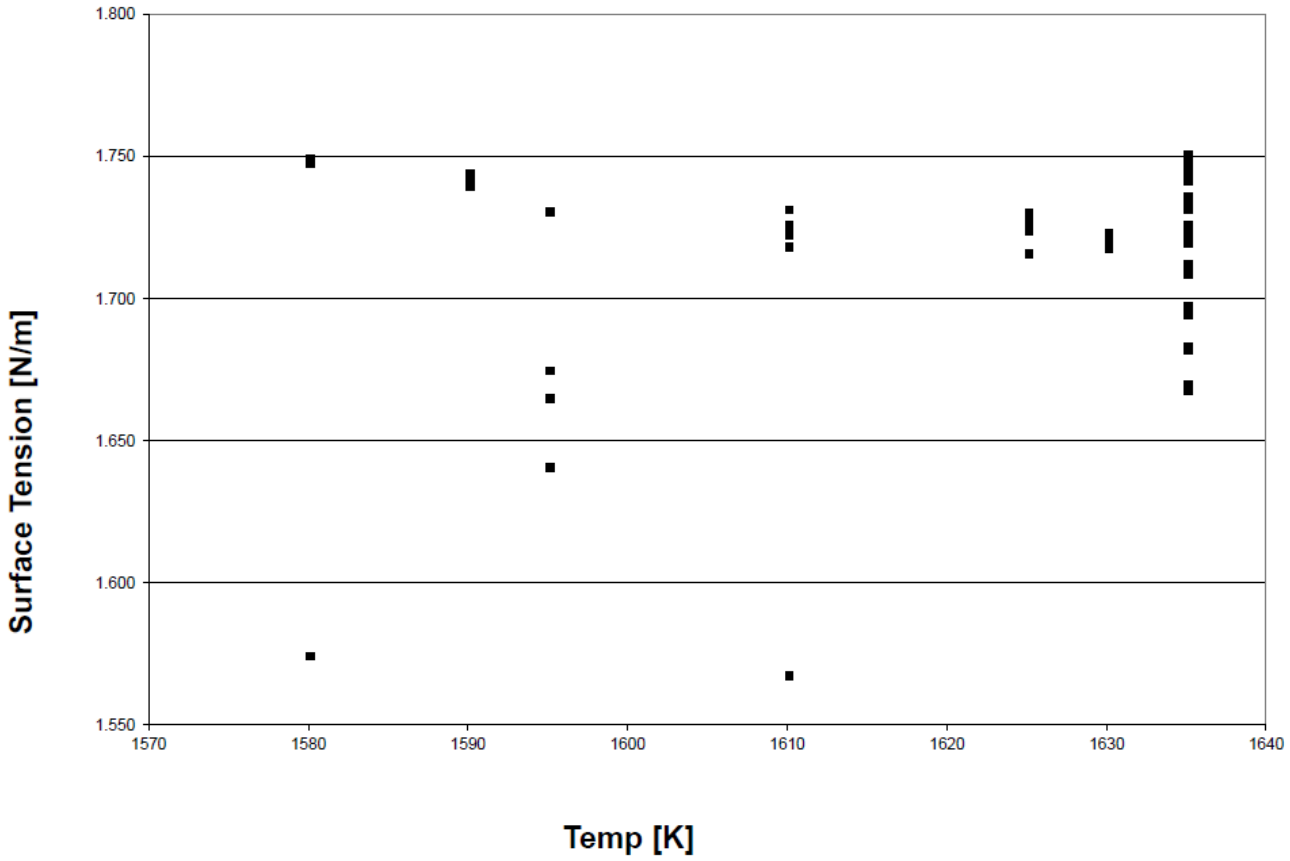


Oxygen partial pressure control over time. Set to 10^{-18} bar.



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.**

Acknowledgements

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