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Design of a High Temperature Thermal Contact Resistance Measurement System

Robert A. Sayer and Thomas W. Grasser
Sandia National Laboratories
Albuquerque, NM 87185

Motivation

- Thermal contact resistance at the interfaces of mating materials is a major barrier to heat transfer in many components of interest.
- Experimental quantification of typical values is sparse, especially in abnormal thermal environments.
- Values must often be selected from room temperature results, or in extreme cases, ignored completely
- This project utilize a high temperature measurement system to determine contact resistance for materials of interest.

Thermal Contact Resistance (TCR)

- TCR arises due to imperfect contact at mating interfaces caused by
  - Surface roughness
  - Surface flatness
  - Flaws
- Real area of contact is several orders of magnitude less than the apparent area of contact

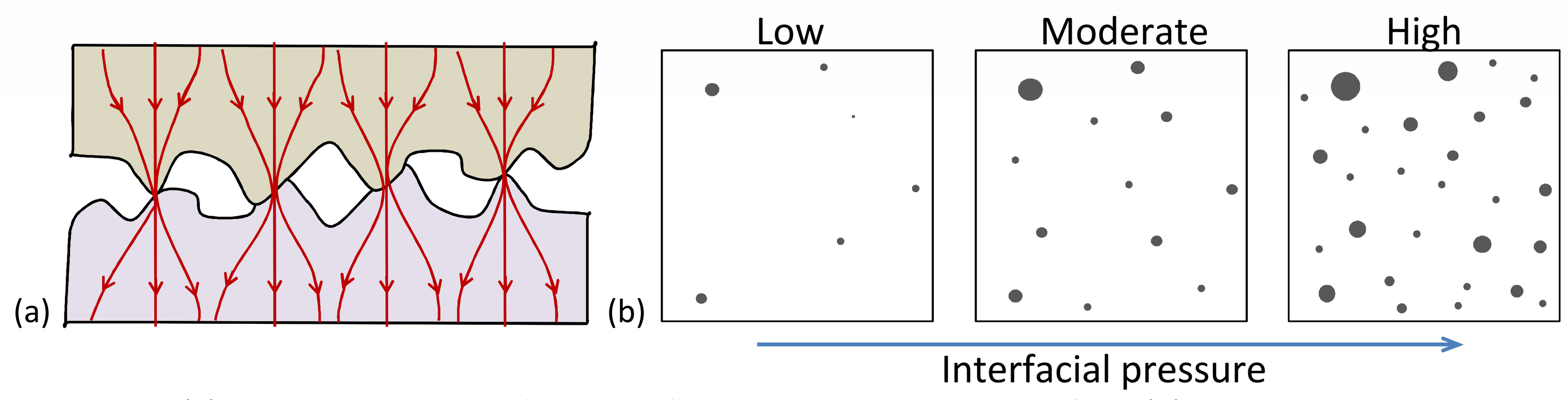
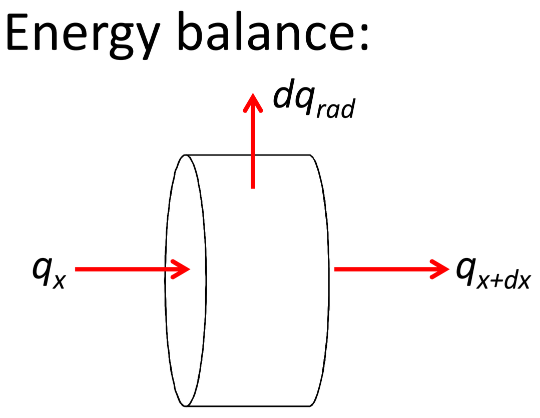


Figure: (a) 2-D representation of the heat flux across a contacting interface. (b) Contact area as a function of applied interfacial pressure.

Theory

- Assume 1-D steady-state heat conduction
- Energy balance:



$$q_x = q_{x+dx} + dq_{rad}$$

where

$$q_x = -kA\frac{dT}{dx}$$

$$q_{x+dx} = q_x + \frac{dq_x}{dx}dx$$

$$dq_{rad} = \varepsilon\sigma P dx\left(T^4 - T_0^4\right)$$

- Governing equation:

$$k\frac{d^2T}{dx^2} + \frac{dk}{dT}\left(\frac{dT}{dx}\right)^2 - \frac{\varepsilon\sigma P}{A}\left(T^4 - T_0^4\right) = 0$$

- Boundary conditions

(1.) $T(x=0) = T_1$ (2.) $T(x=L) = T_2$

- Iterative solution

$$A\int_0^T k(T)dT = \frac{1}{2}\varepsilon\sigma P\left(T_{pv}^4 - T_0^4\right)x^2 + xA\int_0^{T_1} k(T)dT + \frac{A\int_0^{T_2} k(T)dT - A\int_0^{T_1} k(T)dT}{L} - \frac{1}{2}\varepsilon\sigma P\left(T_{pv}^4 - T_0^4\right)L$$

Nomenclature

A	Area
k	Thermal conductivity
L	Length
P	Perimeter
q	Heat rate
T	Temperature
x	Location
ε	Emissivity
σ	Stefan-Boltzmann constant

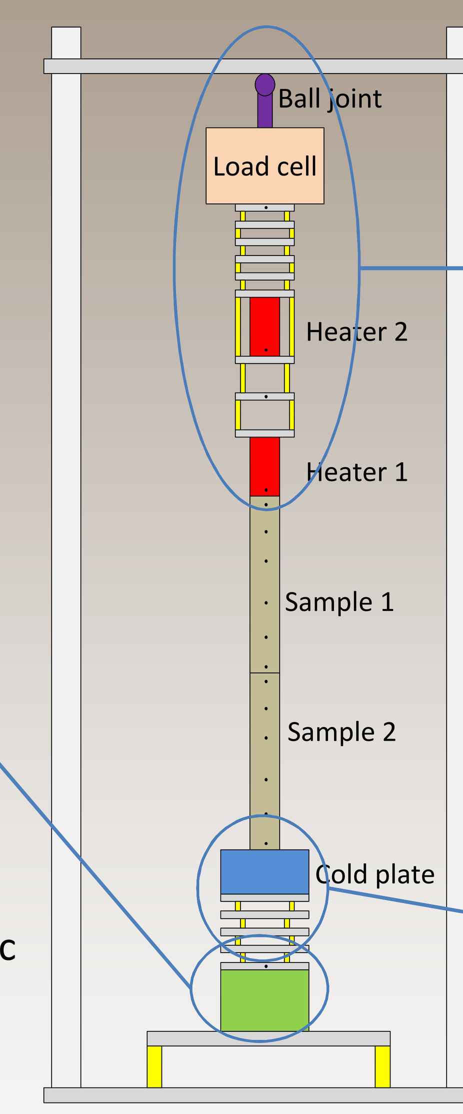
subscripts

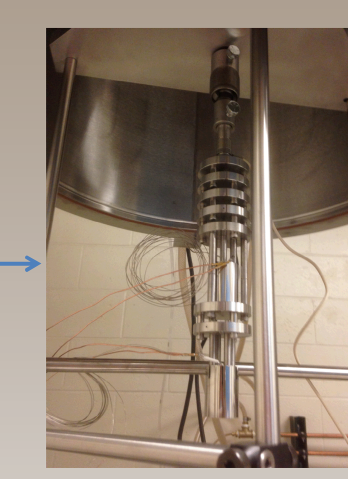
0	Ambient
1,2	Locations
pv	Previous value
rad	Radiation

Experimental System

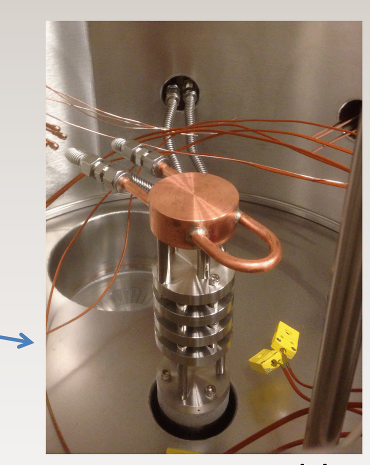
Kurt J. Lesker bell jar vacuum system

Custom pneumatic actuator





Top assembly



Bottom assembly

High Temperature Results

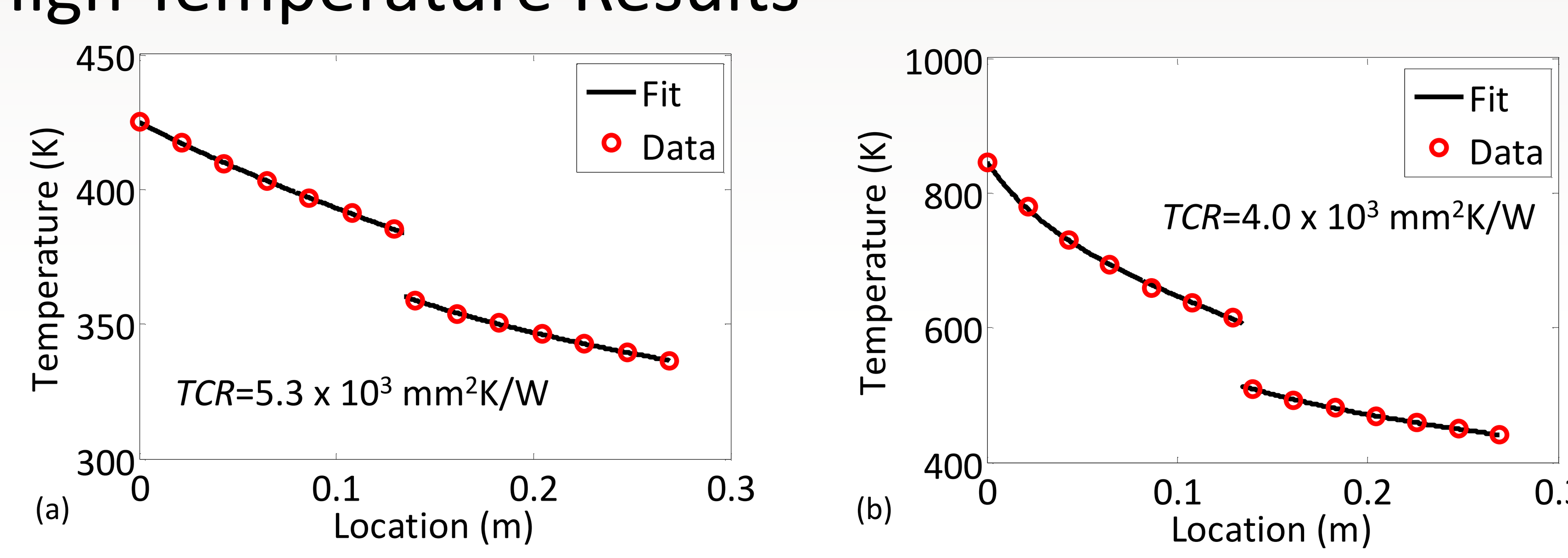


Figure: Experimental measurements and data analysis fit for 304 stainless steel contacts at (a) low and (b) high temperature.

Room Temperature Results

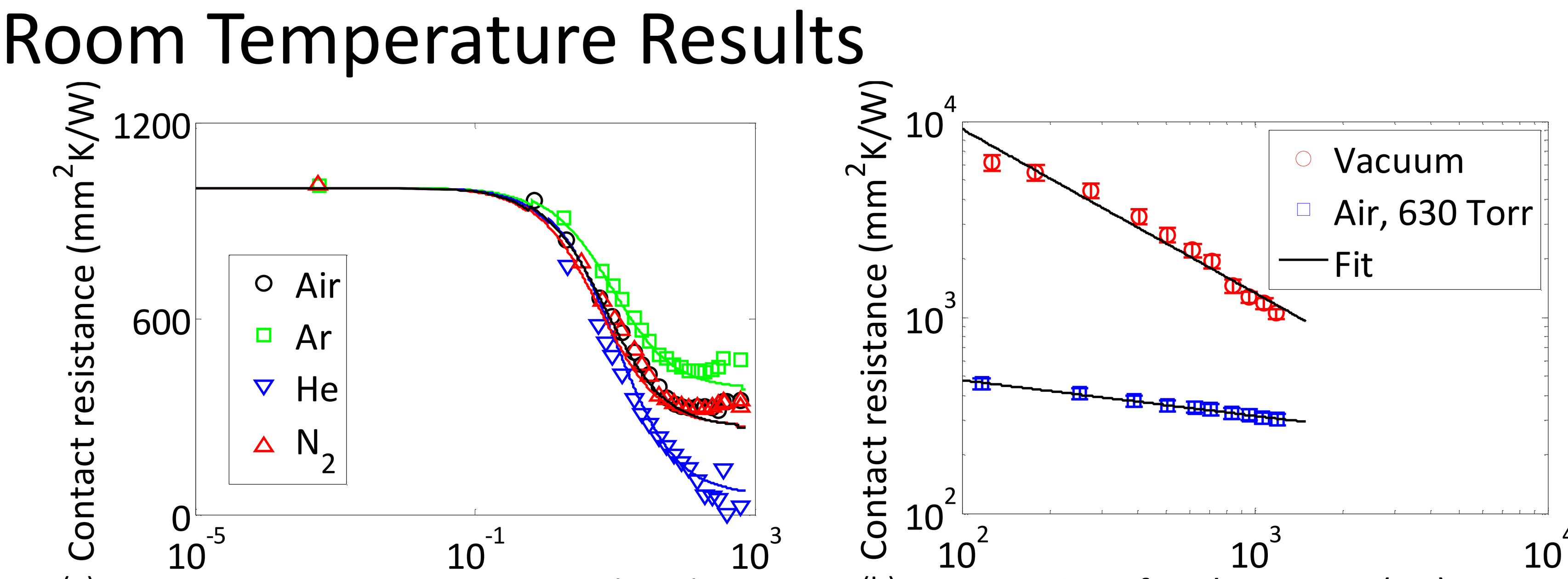


Figure: TCR as a function of (a) gas pressure and (b) interfacial pressure for 304 stainless steel.

Select Publications

- Sayer, R. A. (accepted), "Generalized Procedure for Improved Accuracy of Thermal Contact Resistance Measurements for Materials with Arbitrary Temperature-Dependent Thermal Conductivity," *Heat Transfer Engineering*.
- Sayer, R. A. (in review), "Thermal Contact Conductance as a Method of Rectification in Bulk Materials," *Heat Transfer Research*.
- Hodson, S. L., R. A. Sayer and T. W. Grasser (submitted), "High Temperature Thermal Contact Resistance Measurements of Metallic Interfaces" *HI TEMP 2014*, Santa Fe, NM.

Acknowledgment

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