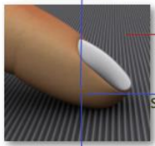
Effusivity and Thermal Transient Measurements of Composite Materials for Human Factors and Industrial Environmental Safety

Introduction

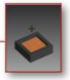
What: An advanced thermesthesiometer has been developed to measure the heat flux, touch-force, and internal temperature profile of multiple test surfaces under transient conditions. This instrument is used to characterize various materials for end-use conditions and aims to quantify the potential for thermal hazards in connection with human subjective testing.
Why: Materials in industrial environments can dissipate a significant amount of heat. It is not always possible to theoretically predict this process as many thermal systems are often composed of complex composite shells or housed in materials that vary in surface texture.
How: A suitably chosen material with thermal characteristics similar to that of human tissue is thermally regulated using a programmable logic controller (PLC). An automated driving mechanism provides variable touch-occurrences and pressures over specially engineered test-surfaces; each with varying effusivities and surface texture.

Thermal Response of Human Tissue

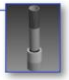
- Nerve endings reside within the dermis, at a depth of 80µm
- By the time you sense pain, the outer layer (epidermis) of the skin has already been damaged

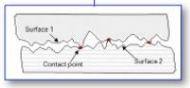


Warm Test Surface Temperature Control



Simulated Tissue Temperature Control





- The thermal response depends on the surface area over which contact occurs

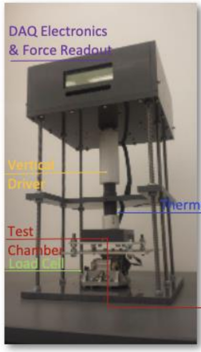
- Heat transfer between two objects is proportional to the density, heat capacity and thermal conductivity of each object, i.e. the effusivity:

$$\lambda = \sqrt{\kappa \rho c_p}$$

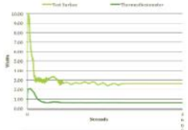
- Unfortuantely, fundamental heat flow is typically not sufficient for calculations involving surface roughness and complex composites
- A room temperature vulcanizing (RTV) silicone can be mixed with Aluminum Oxide (Al_2O_3) to obtain a weighted thermal inertia similar to that of human tissue, e.g. 60% Al_2O_3 + 40% RTV

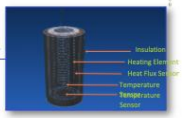
Instrumentation

This instrument includes a test chamber to secure novel composite structures for heating, Kapton (low thermal inertia) heating elements, a load cell for touch force measurements, heat flux & temperature sensors for feedback control and precision, a mechanical driving mechanism, automation and readout hardware/software for repeatability and measurement, as well as a novel silicone mixture to simulate human tissue

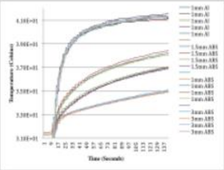


- Fixed Duty Cycle Upon Contact

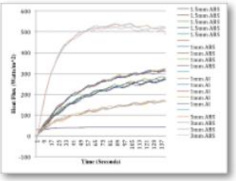




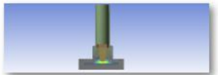
Steady-State Thermal Response

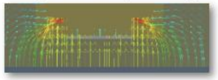


(Left) The temperature response of several test materials, initially heated to 44 ℃, contacting the simulated skin, held initially at 32.5 ℃. The legend describes each material, e.g. "1.5mm ABS" is a composite made of 1mm Aluminum underneath 1.5mm of ABS plastic. **(Below)** Similar to the temperature response paramaters given (Left), the heat flux response is shown below..

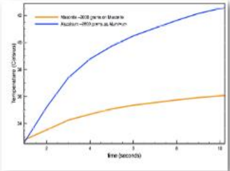


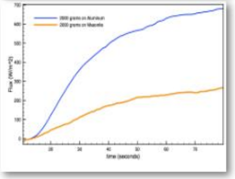
FEA (ANSYS) simulations aid in design and sensor positioning





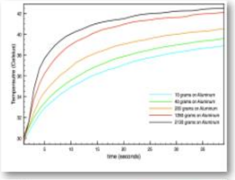
Effusivity

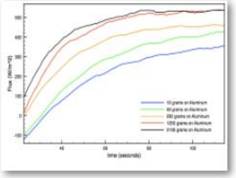




- **(Top)** Comparing the temperature response of the thermesthesiometer (regulated at 32.5°C) touching a 44°C sheet of Aluminum and Masonite. **(Bottom)** Heat flux.
  $\lambda_{Aluminum} > \lambda_{Masonite}$

Contact Resistance





- **(Top)** The temperature response of the thermesthesiometer (regulated at 32.5°C) coming into contact with a 1mm sheet of 6061 Aluminum under several different contact forces. **(Bottom)** Heat flux.

References

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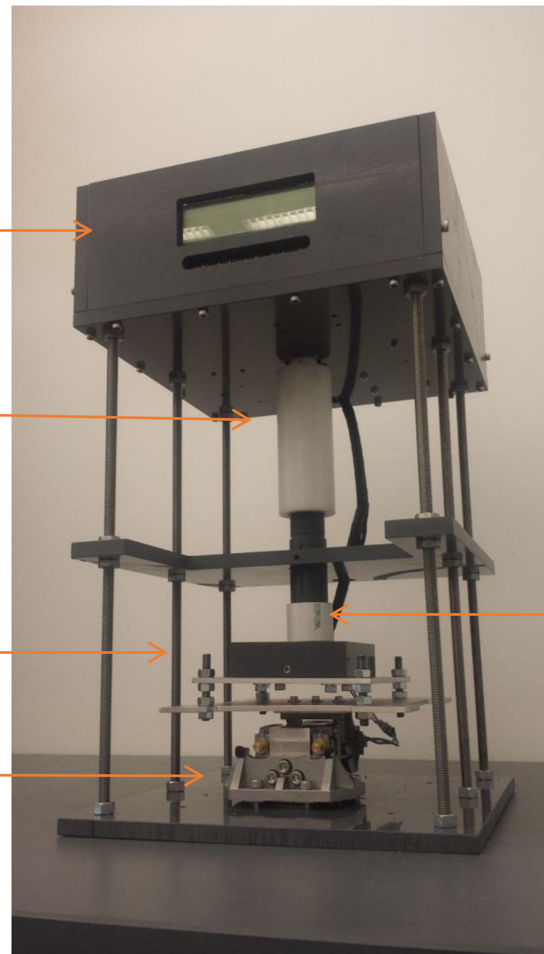
Control System Features



DAQ and Electronics

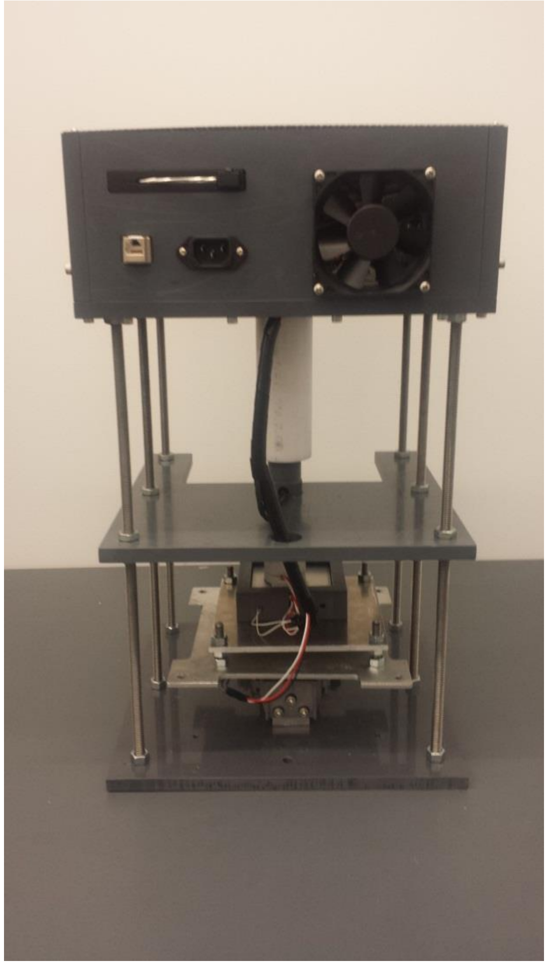
- ✓ DAQ (National Instruments)
  - Digital Out (32 Channel)
  - Analog Read (4 Channel)
- ✓ Micro-controller with Bipolar Stepper Motor
- ✓ Miniaturized heat flux sensor with $\pm$3% accuracy
- ✓ Pt100 RTD with $\pm$.1°C accuracy
- ✓ MSR45 Heat Flux Data Logger
- ✓ Solid-state Relays for PID Controls
- ✓ 12V Power Supply for Stepper and Load Cell
- ✓ 5V Power Supply for Digital Out, Relays and Microcontroller
- ✓ Cooling Fan
- ✓ Kapton, resistive heating element (21^{0}C - 200°C)
- ✓ Load Cell (0 to 6000 grams $\pm$.1g)
- ✓ Housed in a PVC shell:
  - .5'' thick walls
  - Low enough conductivity k = $.19\frac{W}{mK}$

✓ Breathable grating for air circulation

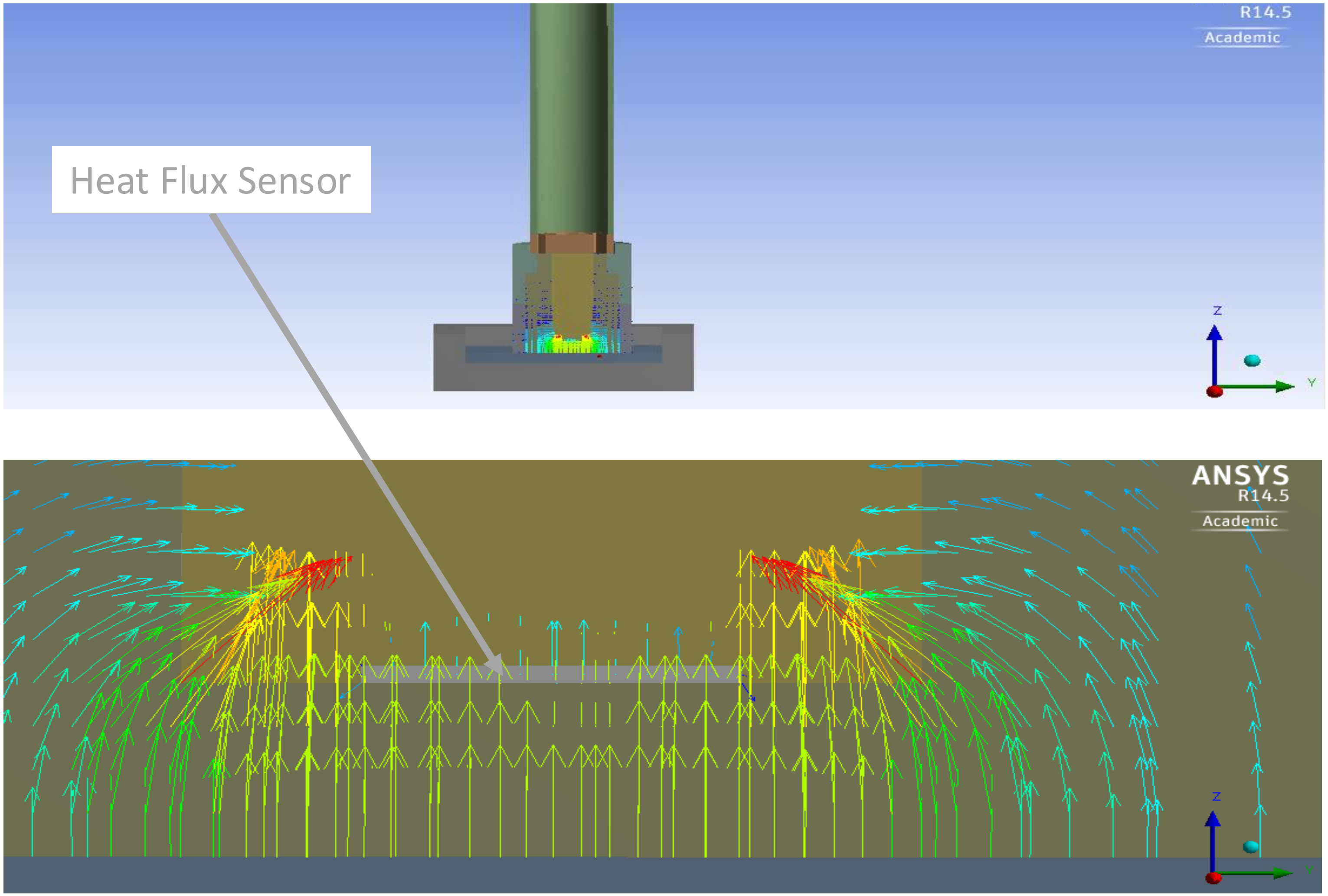
✓ USB Hub for heat flux sensor data and uploading code to the micro-controller.

✓ Ethernet Cable for DAQ System

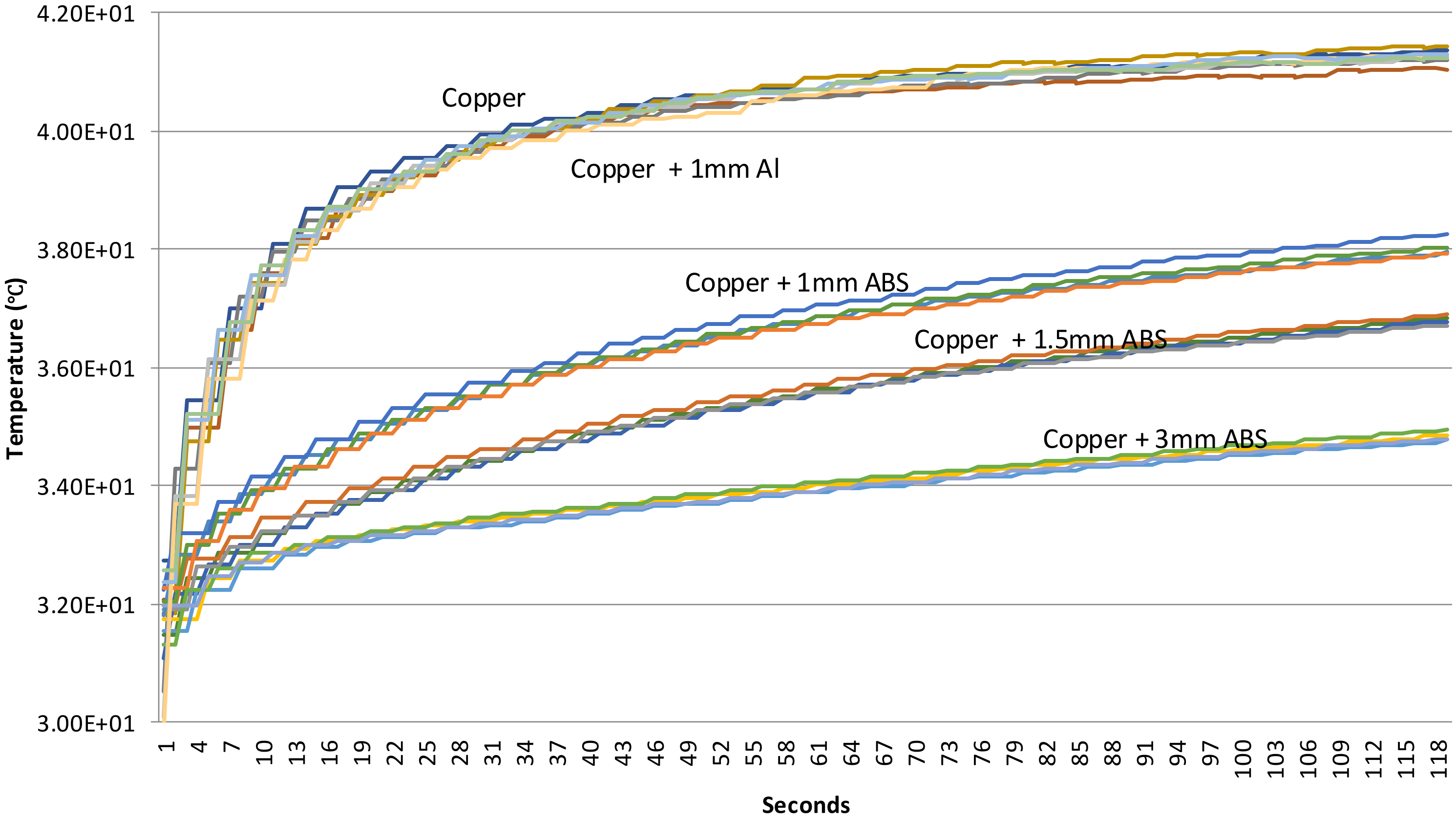
✓ Power Outlet

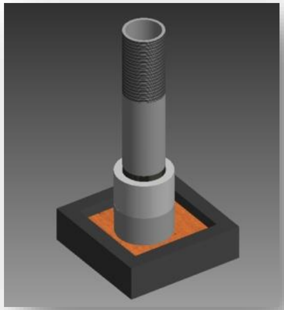


Heat Flux Sensor Design Considerations: ANSYS Simulations

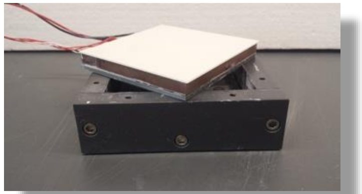


Testing Composite Thermal Response: Copper + ABS 44 Surface VS 32.5 Test Surface

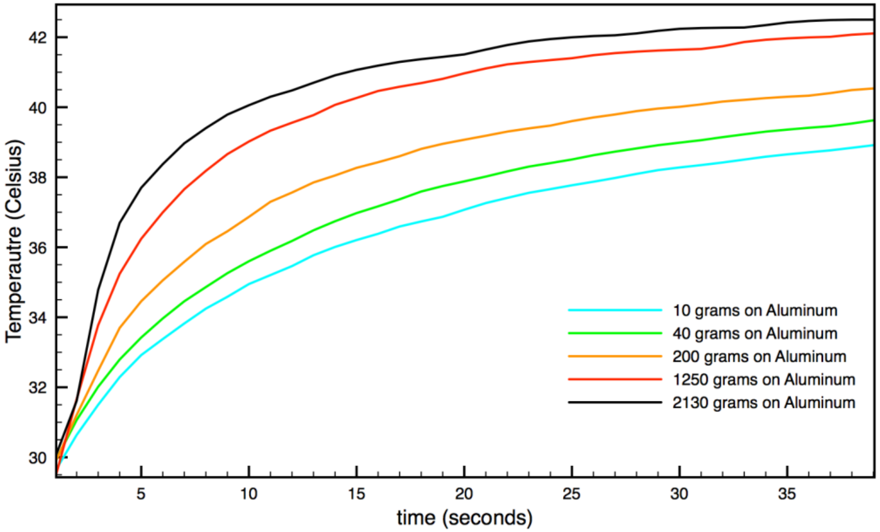


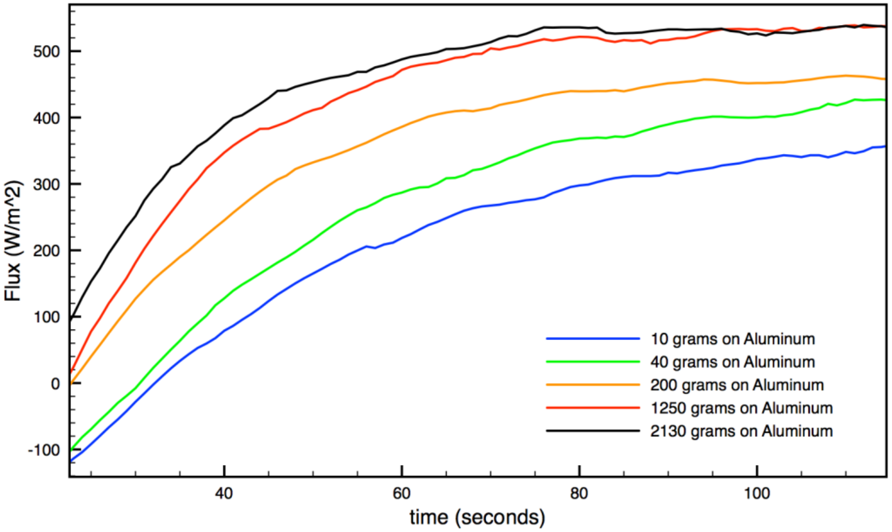


Thermal Response



Setpoint at T = 42°C





- Heat Flux Readout

- PID Control
- Data Logging

Automated Instrument