Understanding Vacuum Furnace Temperature Measurement Issues

Presented By: William R Jones, CEO
Solar Atmospheres Inc., www.solaratm.com

Technical Contributors:
Virginia M Osterman, Ph.D. Senior Scientist, Solar Atmospheres Inc.
Rèal Fradette, MSME, Senior Consultant, Solar Manufacturing Inc.

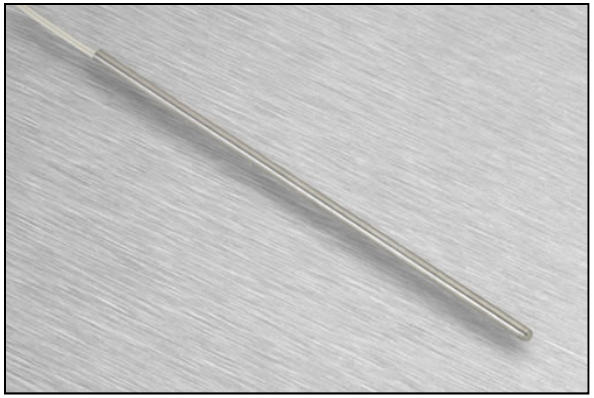
Overview

- Thermocouple construction
- Types of thermocouples
- Control thermocouple placement
- Temperature uniformity in a furnace
- Use and placement of work thermocouples
- How work material properties affect heating rate
  - Emissivity, surface finish, mass, surface area
- Dummy blocks selection and placement
- Non-electrical temperature monitoring devices

Temperature Measurement
Optical Pyrometer

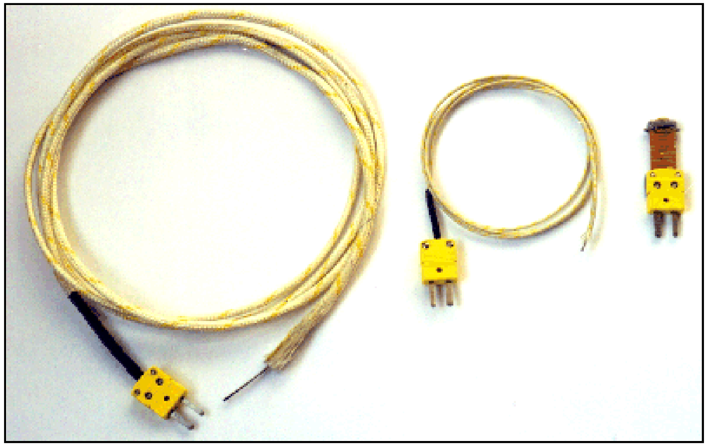
Temperature Measurement Sensors

Convert an EMF electrical signal to °C or °F



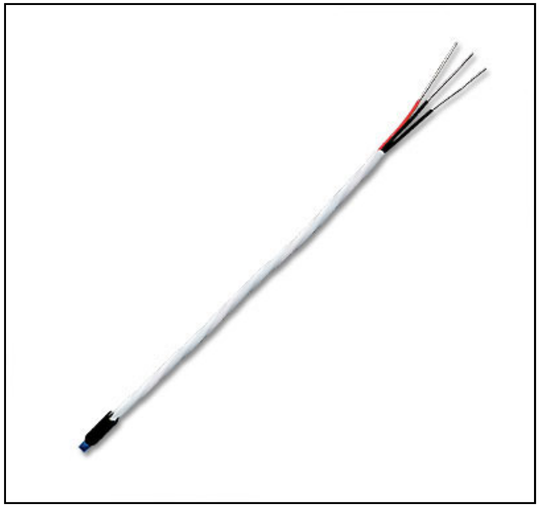
Thermistor

(thermal resistor)



Thermocouples

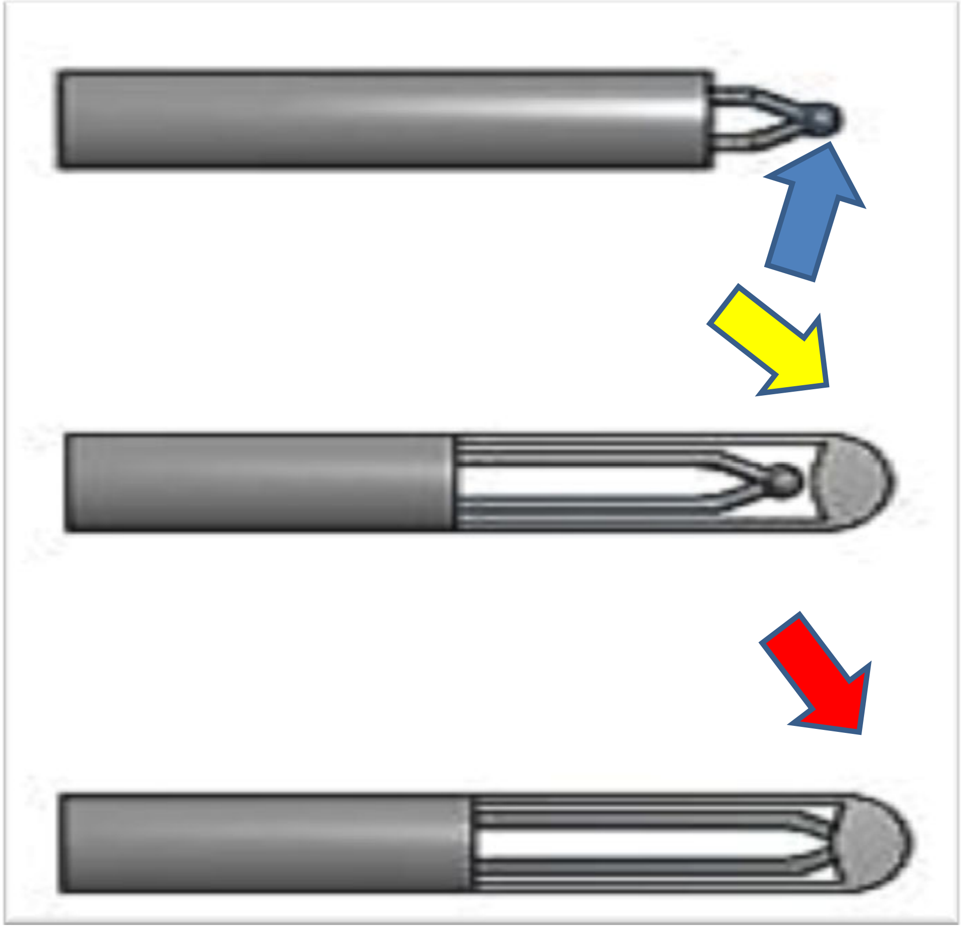
(thermoelectric couple- Seebek Effect)



RTD

(resistance temperature detector)

Sheath Thermocouple Construction



Exposed Wire:
Rapid response time
Affected by contamination

Ungrounded:
Longer response time
Shielded from contamination

Grounded:
Faster response
Shielded from contamination
Longer life at high temperatures

Picture reference :http://www.correge.fr/thermocouple-en.html

TC Construction Advantages/Disadvantages

Wire Size

- Smaller diameter wires
  - Faster response times
  - More fragile
  - Low/moderate temperature applications

- Larger diameter wires
  - Longer life
  - High temperature applications

Types of Thermocouple Wire

ANSI Type Symbol	Wire Alloys	Temperature Range °C	Temperature Range °F	Calibration Tolerance %	Application Advantages
K	Chromel®(+)/Alumel® (-) (Nickel-Chromium/Nickel-Aluminum)	0 to 1250	32 to 2300	+/-0.4	**Work TC, all atmospheres** **Accurate to high temperatures, limits on reuse**
N	Nicrosil (+) /Nisil (-) (Nickel-Chromium-Silicon/Nickel-Silicon)	0 to 1250	32 to 2300	+/- 0.2	**Work TC, all atmospheres** **Greater accuracy and reuse at high temperatures**
S	Pt – 10% Rh (+) /Pt (-) (Pt- Platinum and Rh – Rhodium)	0 to 1450	32 to 2800	+/- 0.1	**Furnace control TC** **Expensive, fragile sheath** **High accuracy at high temperature**
W3	W-3% Re (+)/W - 25% Re (-) (W- Tungsten, Pt-Platinum and Re-Rhenium)	400 to 2300	800 to 3800	+/-0.25	**Furnace Control TC** **Expensive** **Very high temperatures** **Wire becomes brittle after one cycle**

Furnace Control and Over-temperature TCs

Alumina (Mullite) Sheath : Fragile

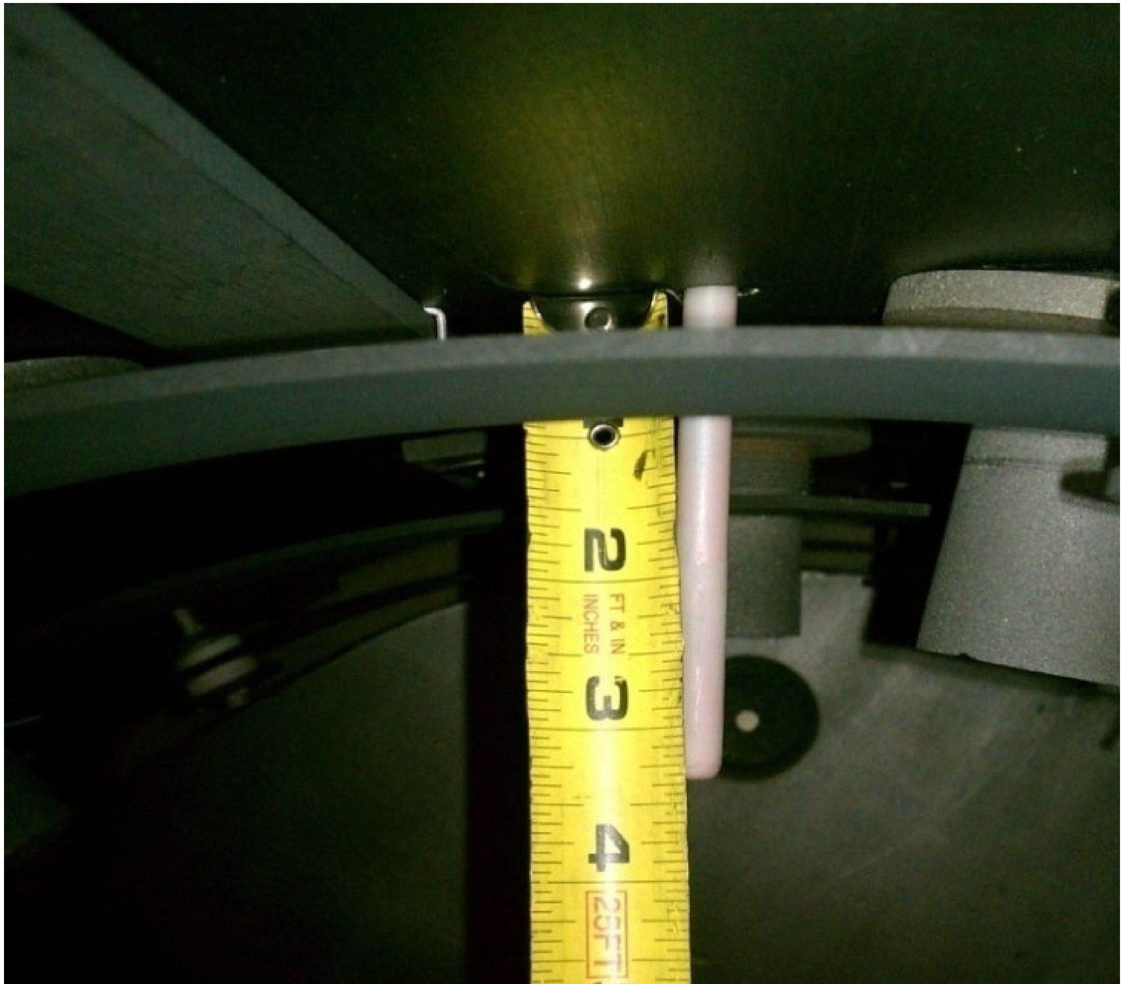
Furnace: Type S - up to 2800°F (Pt – 10% Rh) (+) /Pt (-)

Higher Temperature: Type B – 3200°F (Pt/Rh 70%/30%) (+) – Pt/Rh 94%/6%(-)

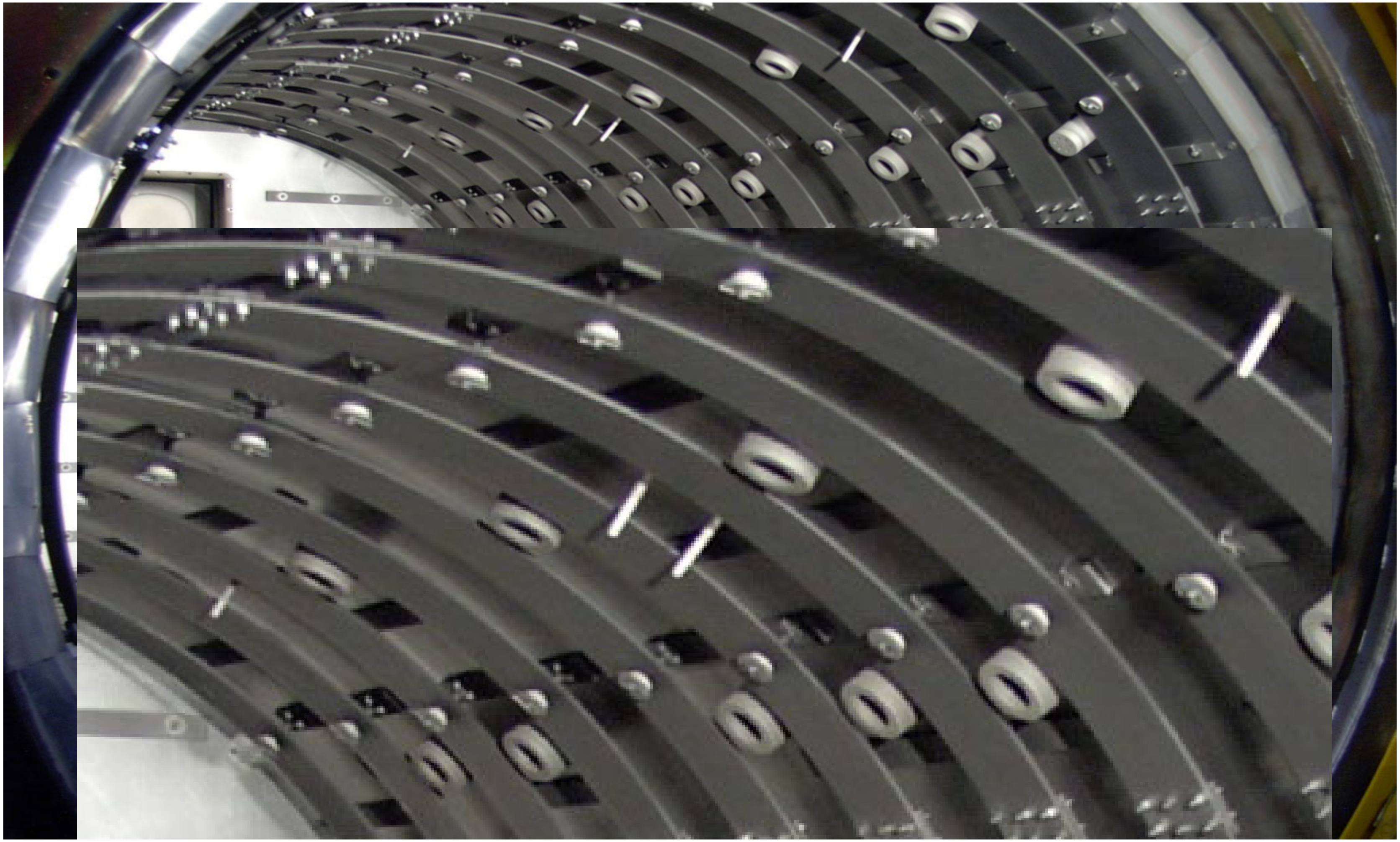
External View of Furnace Control TCs

Placement of Control TCs

Proper placement of control TCs relative to the heating elements is critical!!

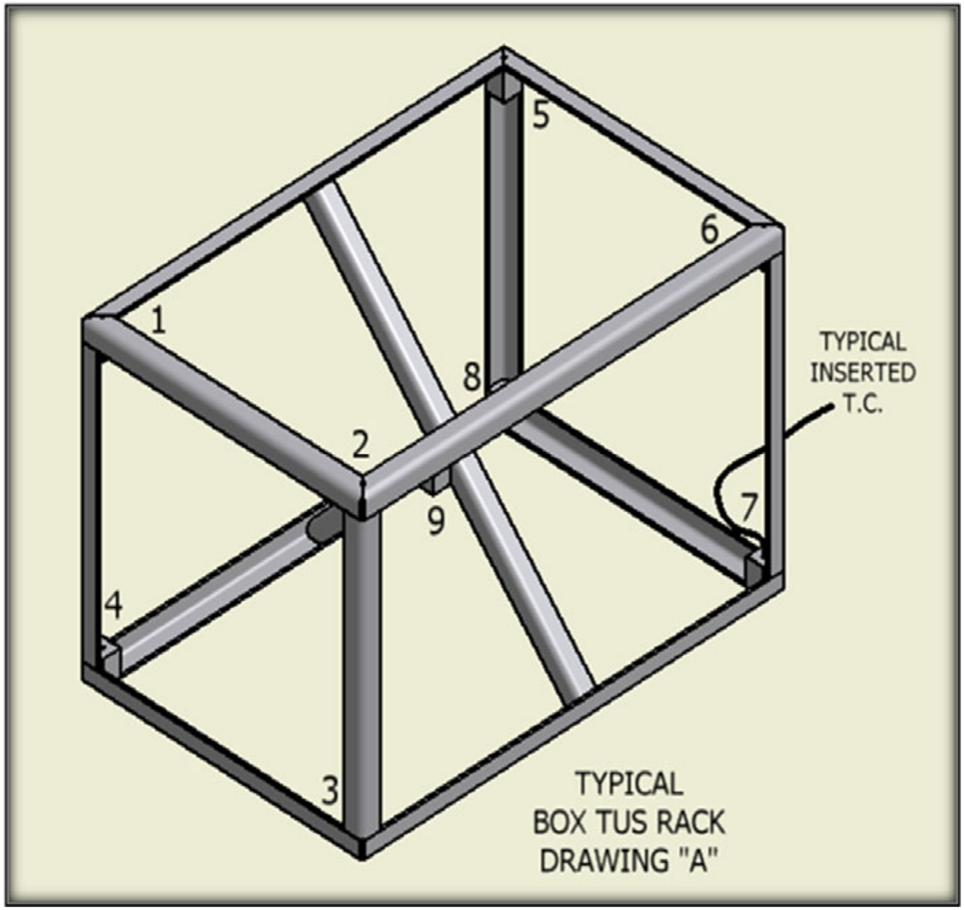


Location of Furnace TCs in the Hot-Zone



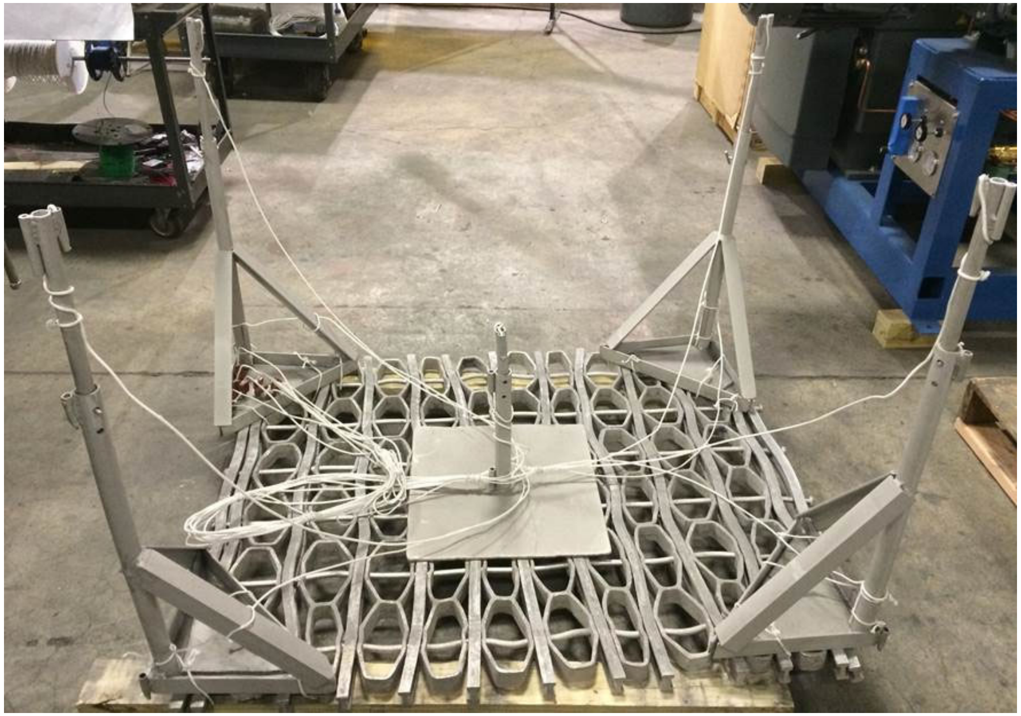
Proper Thermocouple Placement for Temperature Survey (TUS)

- This is a typical box configuration with heat sink blocks located at the corners and center position.
- Design limitations for conforming to AMS 2750E
- Not universal for multiple sized furnaces

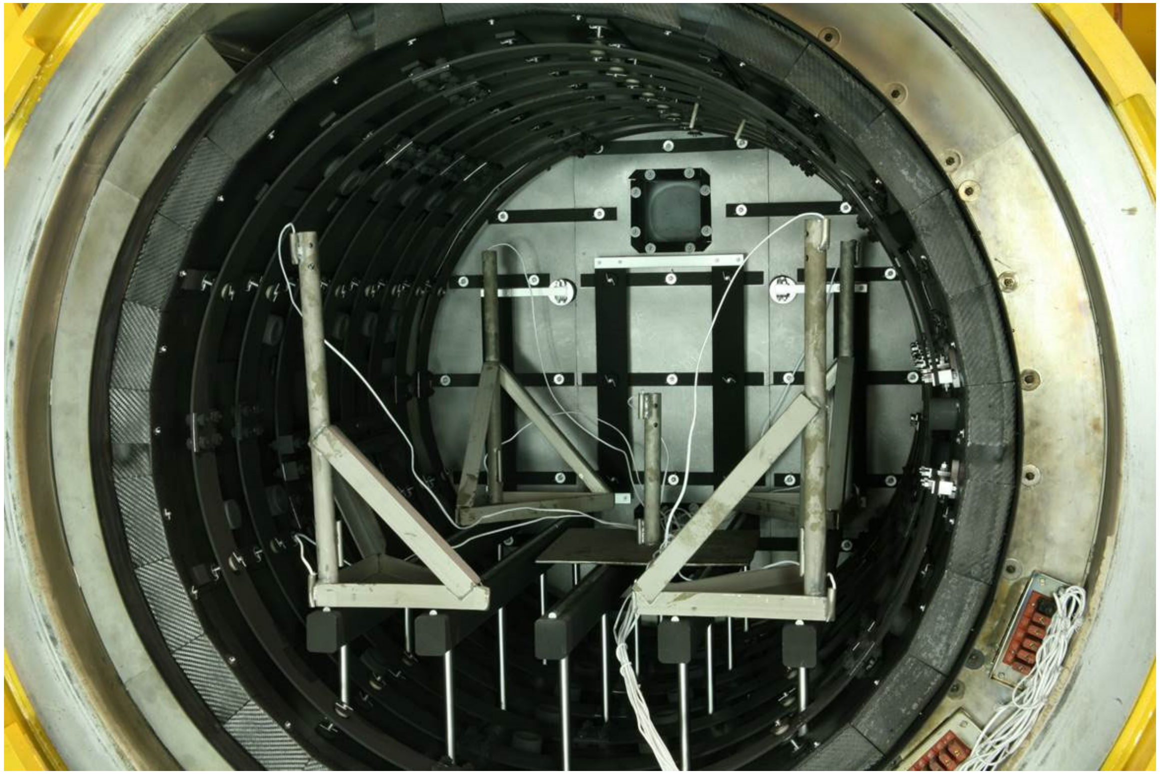


Universal Thermocouple Survey Rack
Meets all TUS Certification Requirements

- Individual corner pipes
- Adjusts vertically to accommodate furnace size
- Positioned at extremes of the working zone
- Top and bottom T/C heat sinks welded to the inner surface
- 8 corner TCs
- 1 Center TC



Furnace Set-Up for TUS



Tolerance
by Furnace Class

- •Class 1 is +/-5°F
- •Class 2 is +/- 10°F
- •Class 3 is +/- 15°F
- •Class 4 is +/- 20°F
- •Class 5 is +/- 25°F
- •Class 6 is +/- 50°F

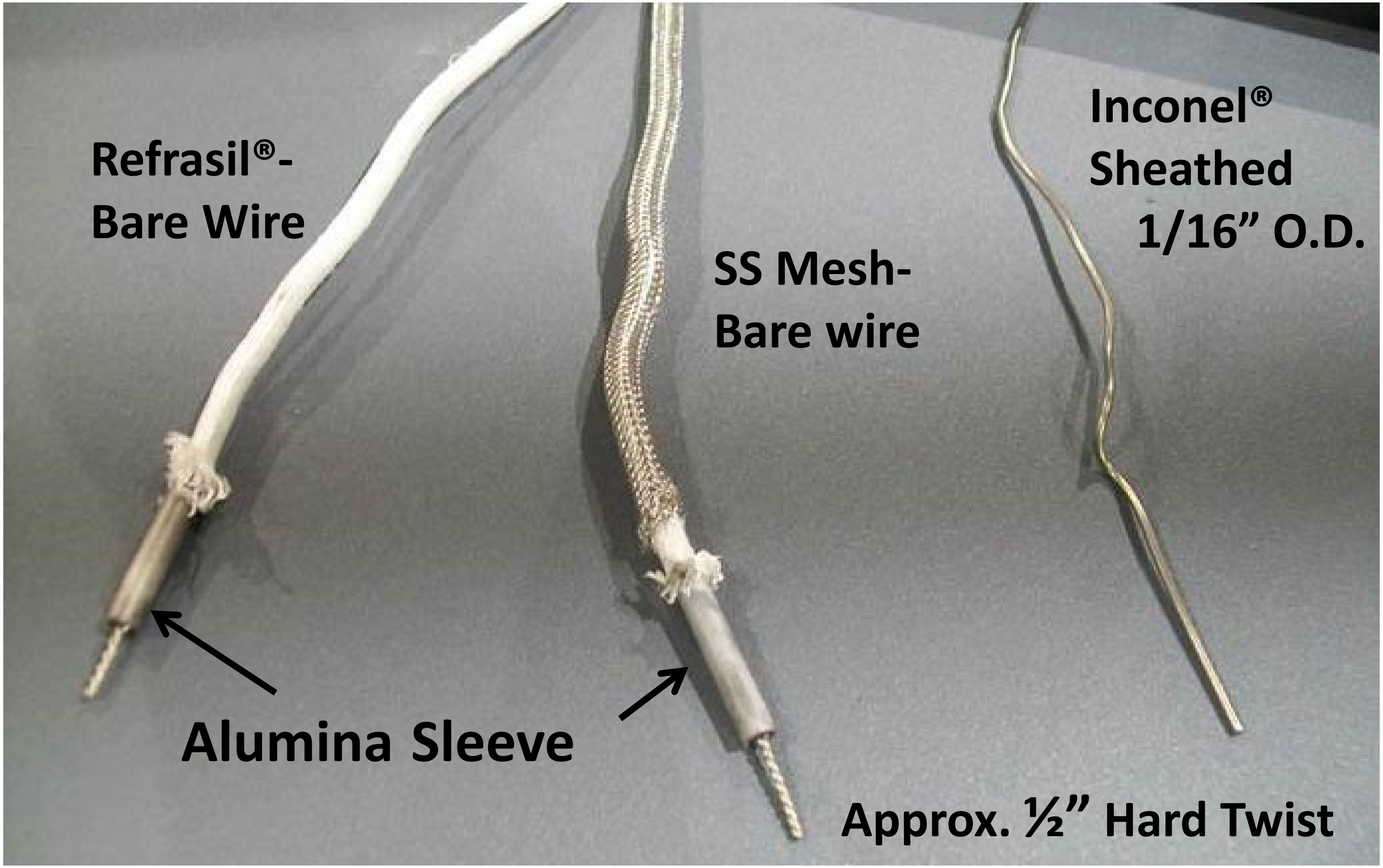
Why Use Workload Thermocouples?

Measure heat transfer from heating elements to the “work. ”

Factors Affecting Heat Transfer

1. Thermal conductivity of part
2. Emissivity/absorptivity of part
3. Mass of the work load
4. Surface area of parts

Typical Work TC Materials



Thermocouple Sheath Materials and Advantages

1) **Refrasil®**: Hygroscopic, can react with parts at high temperatures or with atmosphere; temperature limitation 2250°F
2) **SS Mesh**: More rugged, less friable; temperature limitation 2250°F
3) **Inconel® Sheath:** Non-hygroscopic, resists oxidation. Maximum operating temperature: 2250°F

Thermocouple Characteristics

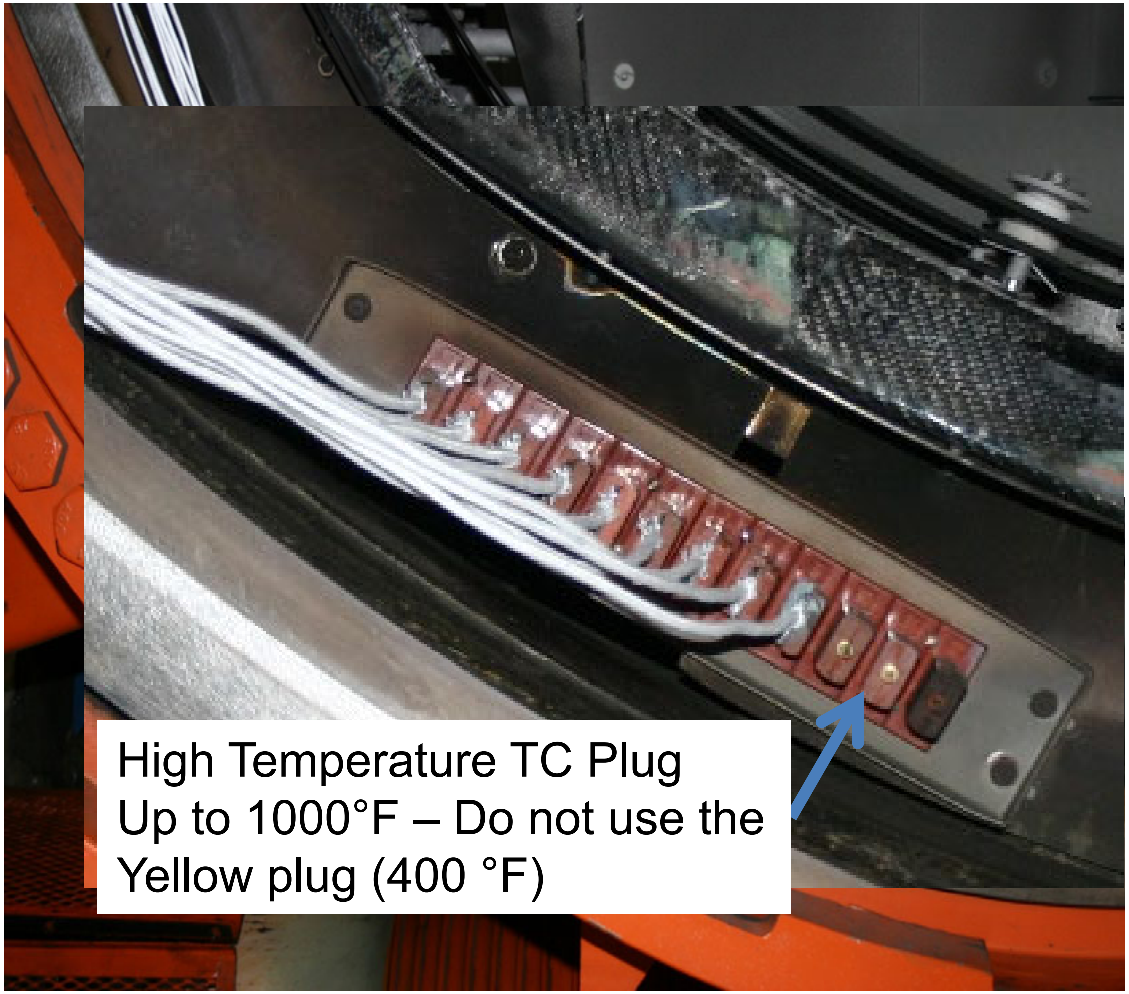
- Type K – is used protected or exposed in in oxidizing, inert or dry reducing atmospheres; exposure to vacuum limited to short time periods; reliable and accurate at high temperatures
- Type N – is used protected or exposed in oxidizing, inert or dry reducing atmospheres; very reliable and accurate at high temperatures
- Type S – Normally used as control and over-temperature thermocouples with alumina protection tubes; very reliable and accurate at high temperatures
- Type W3 – Normally used for control of very high temperature applications; offer the advantage of ductility over pure tungsten thermocouples; Accurate at extremely high temperatures

Typical Work TCs

1) Type K – most common TC, accurate, must recalibrate, losing favor
2) Type N – improved accuracy and extended life and re-use
3) When operating above 2150°F re-use is discouraged owing to temperature drift
4) Aerospace requires new Type K TCs for each run

Thermocouple Jack Panels

- Source of error: dirty jack panel
- Clean regularly
- Dummy jack plugs for unused slots



Thermocouple Feed-through - OLD

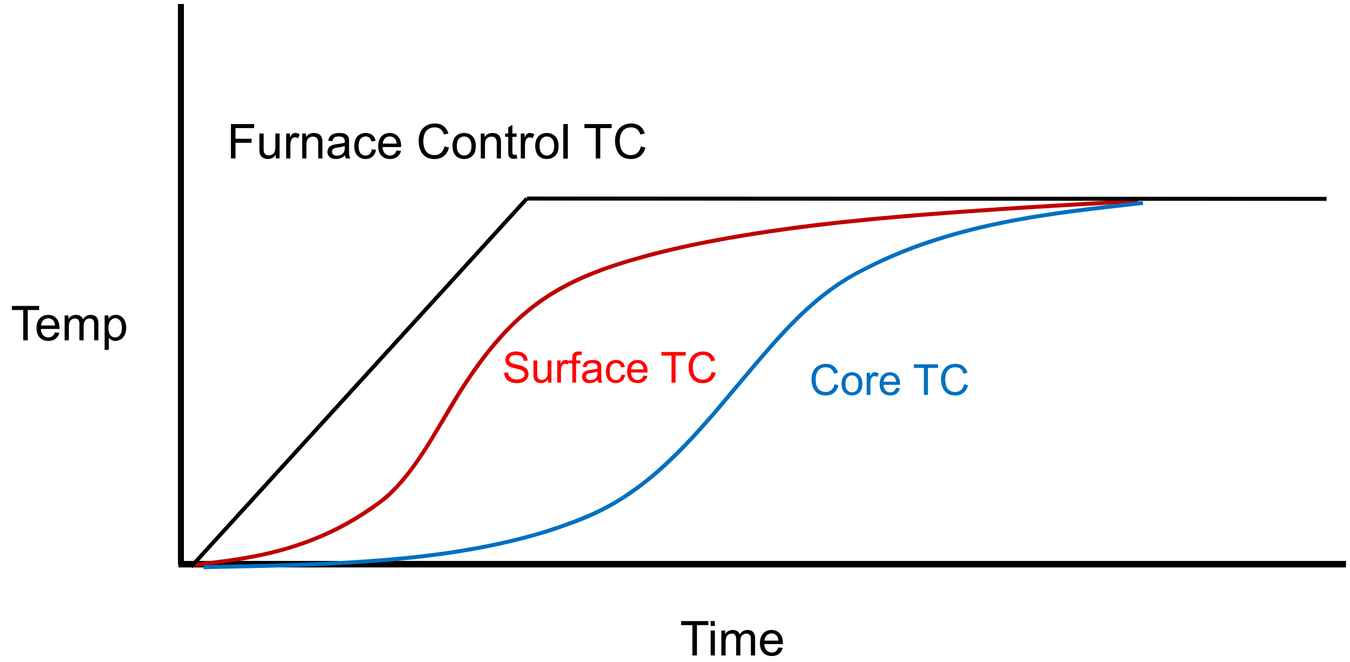
Thermocouple Feed-through- Modern

Correct Work TC Placement

- Place the load thermocouples in existing holes or crevices with the tip, or hot junction, in contact with the metal
- Work TC must be inserted deep into the center of the workload
- Consider the area most shielded from the radiation or the thickest cross-sectioned part (slowest portion to reach equilibrium)

Workload Thermocouple Placement

!! Proper placement of load thermocouples is critical !!



Correct T/C placement = High quality results

Direct Contact Between Layers

Brass Tubing Annealing

Why Load Thermocouples?

Poor Conductors of Heat:

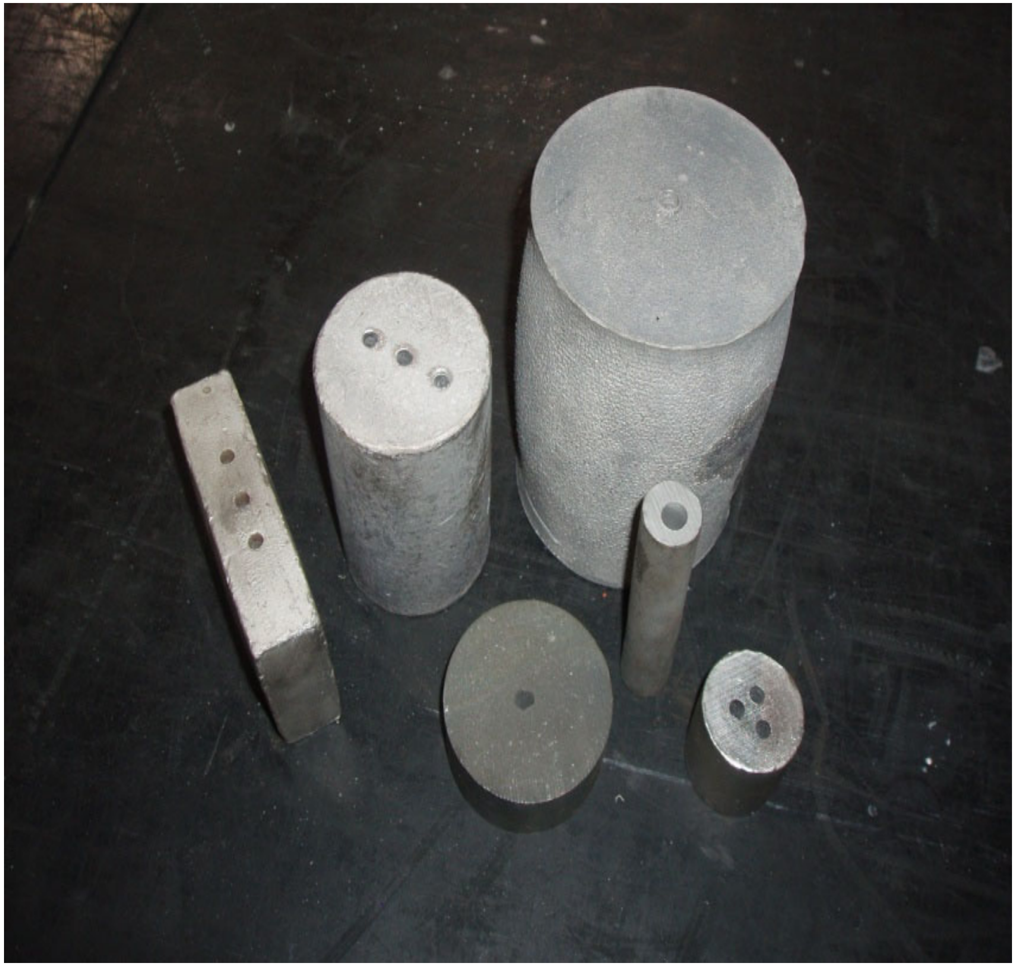
- Loosely coiled and stacked sheet
- Loosely rolled screen
- Loosely coiled wire
- Small fasteners/ ball bearings
- Powders

TC Placement – In the Load

When Surface Contact is Not the Best Option

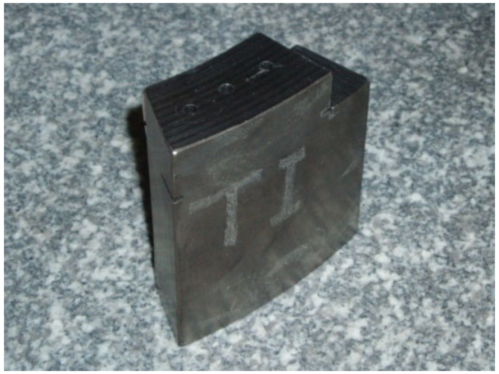
What to Do:

- Use a dummy block
- Mimics the heating profile of the part



Dummy Block Material Selection and TC Placement

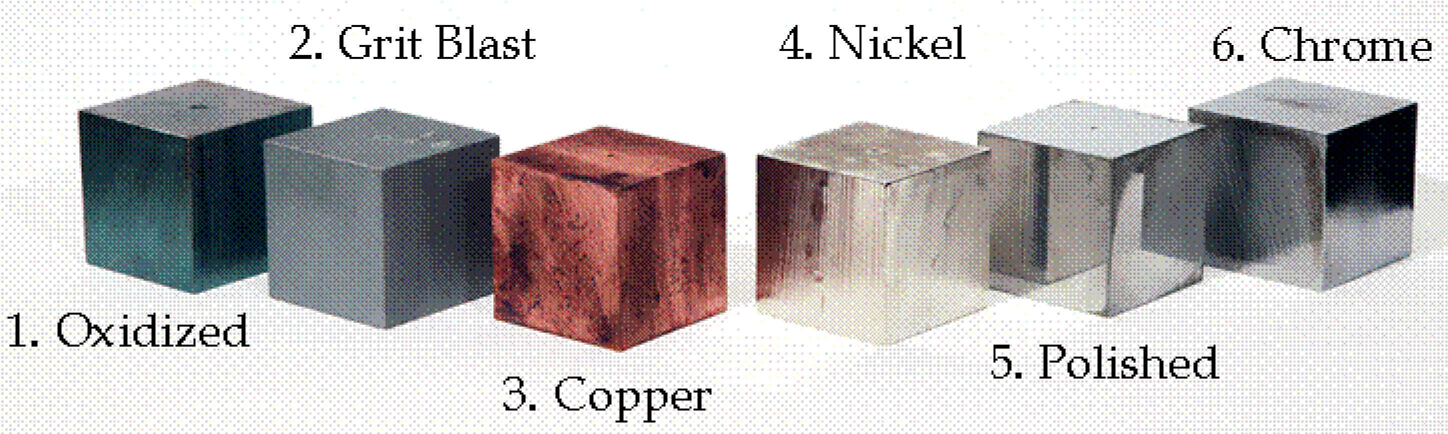
1) Drill TC holes into center
2) Match cross-section to largest part
3) Match the mass of the work
4) Match thermal conductivity
5) Match surface condition
6) Match emissivity



Ti part – Ti Block
Ti heats slower than steel

Cu part – Cu block

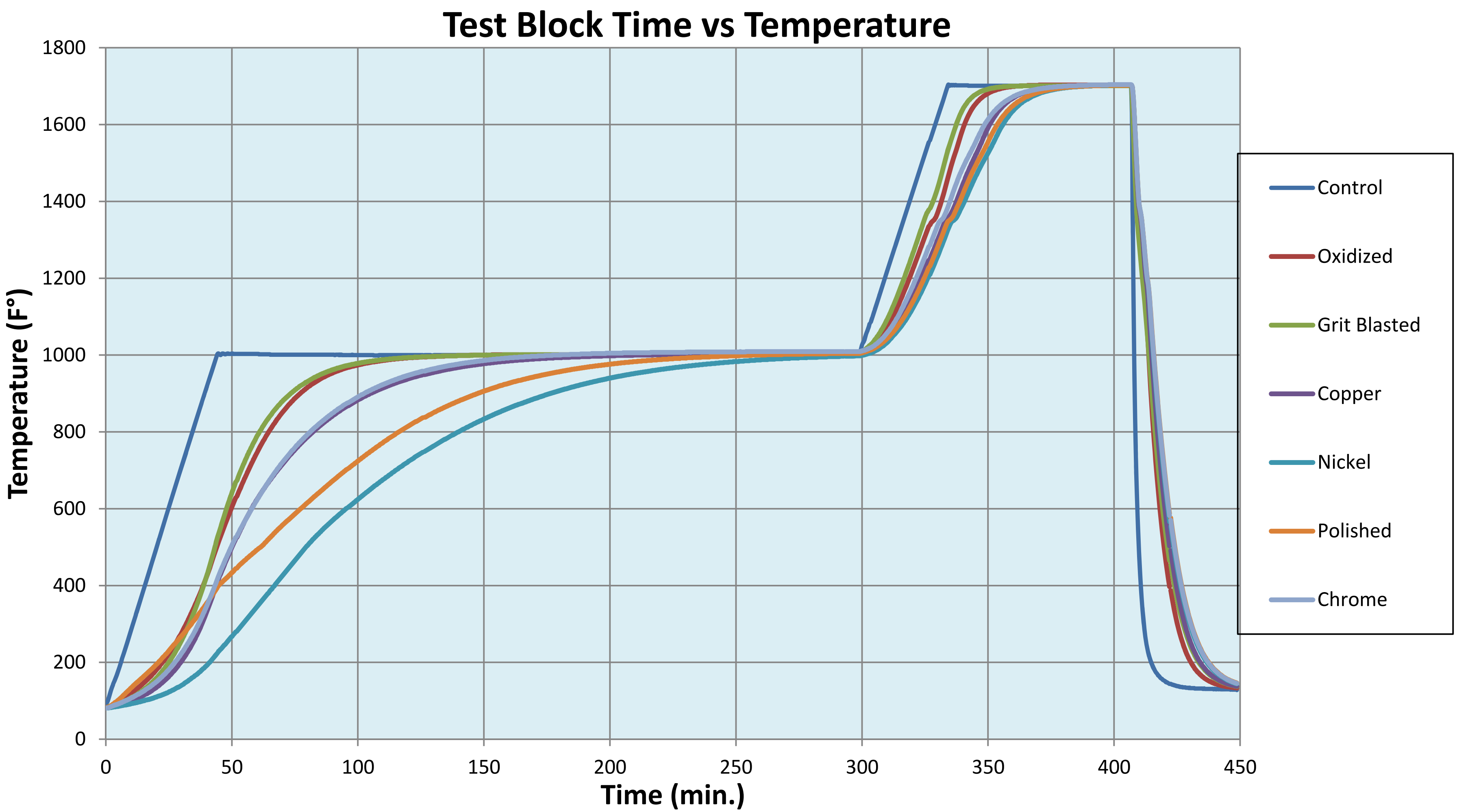
Carbon Steel Dummy Blocks with Various Surface Conditions



Emissivity and Surface Condition Affect Heat Rate

- Emissivity - The ability of a surface to emit radiation
- Absorptivity- ability of a surface to absorb radiation
- ***At thermal equilibrium, the emissivity of a body (or surface) equals its absorptivity***
- A perfect black body (absorbs 100% radiation)
- Test study – same sized dummy blocks, various surface conditions subject to same heat treat cycle and record heat profiles

Surface Condition Effect on Heating



Dummy Block - Same Diameter, Less Mass

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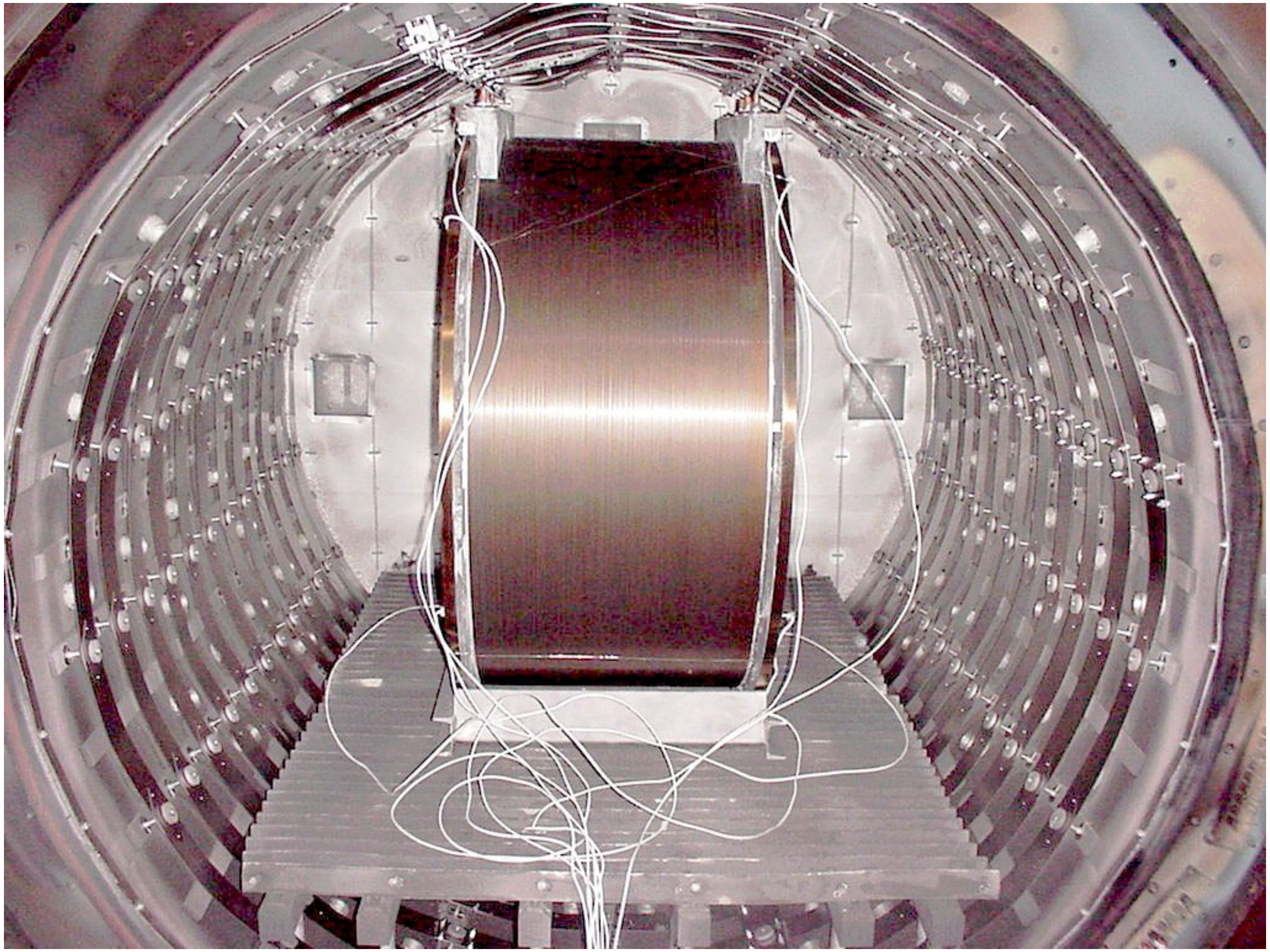
Dummy Blocks in Contact with Parts

Dummy Block/Direct Contact



Improper Choice of Dummy Block (Mismatched Thermal Conductivity)

Part – 6" diameter plastic – non-conducting
Dummy Block – 4" diameter SS – conducting

Conclusions on Using Dummy Blocks

- Radiation heating of work is dependent on mass and surface condition
- Heat rate : Bright and polished much slower than dull and dark
- Rough surfaces heat faster than smooth, reflective surfaces
- Dummy blocks not in direct contact with parts must have similar mass and surface area to mimic the heat rate of load
- Dummy blocks should be periodically re-conditioned to maintain proper surface smoothness and appearance
- One load of material, with a particular surface condition, compared with a load of the same material with another surface condition, could take as much as twice as long to reach the desired temperature

Common Work TC Problems

- **Crossed wires:** If a thermoelectric circuit is backwards, the instrument will read backwards.
- **Loose screw:** A loose screw on the mounting plug will cause a poor connection and possibly shorting.
- **Uncompensated junction:** If materials are used that are not the same as the wires, an error will be introduced.
- **Twisted wires:** If wires touch at a point between the hot and cold junctions, a new hot junction will be produced.
- **Damaged insulation:** If the insulation is damaged, and wires touch foreign materials, an error will be introduced. In addition, this easily allows twisted wires to touch.
- **Poor hot junction:** A loosely twisted or dirty junction will introduce an error.
- **Dirty jack panel or extension wires:** A dirty jack panel is a typical source of error and must be cleaned regularly.

Easy and Cost Effective Method to Monitor Process Temperature – Orton Temp Tabs®

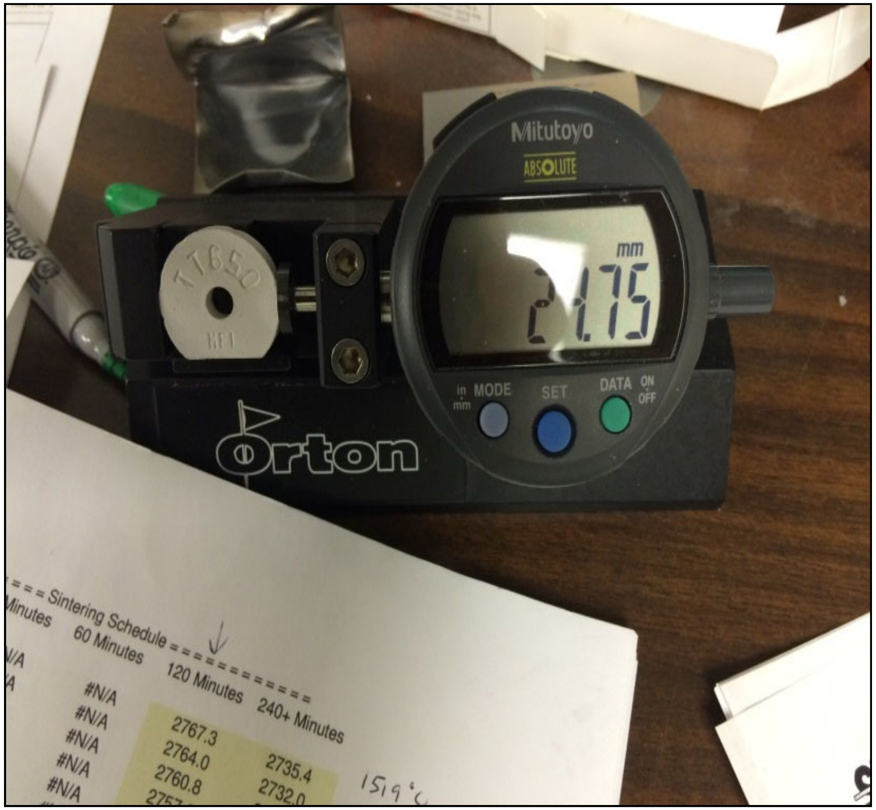
What are Orton Temp Tabs ®?

- Ceramic disks sinter at a controlled rate over a range of temperatures.
- Shrinkage is correlated to maximum temperature in the furnace
- Records peak temperature only

http://www.temptab.com/

Measuring Temp Tabs

- Temp Tabs are measured after they exit the thermal process.
- Best accuracy is achieved using a Temp Tab desktop gauge.
- Place the Temp Tab in the gauge and measure the diameter.
- Other measuring devices can be used as long as they measure to .01 mm.
- Enter the diameter measured into the Temp Trakker software or look up the temperature on a printed chart.



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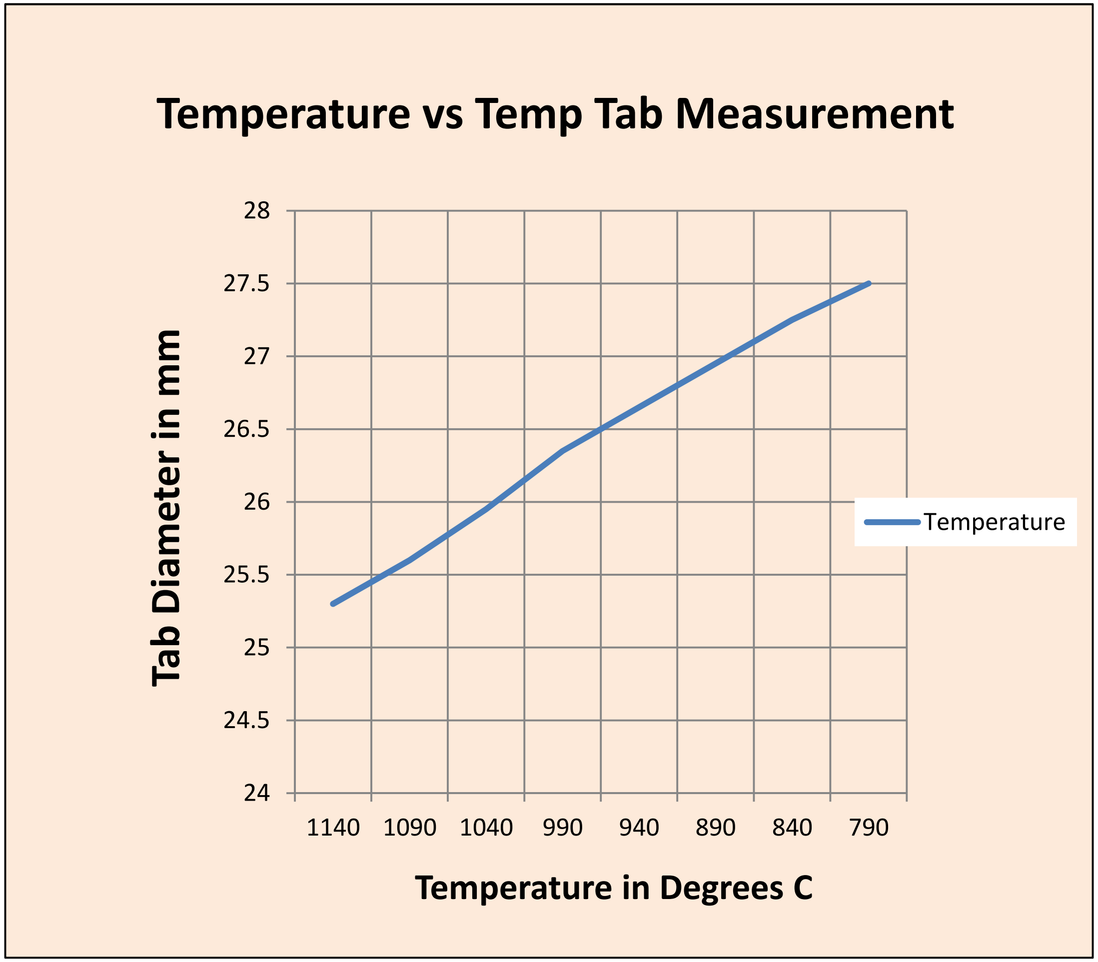
Orton Temp Tab® Measurement vs Temperature Chart



Solar Atmospheres Technical Booklets and Articles

- ***Critical Melting Points and Reference Data for Vacuum Heat Treating***
- ***Temperature Uniformity Surveying of Vacuum Furnaces***
- ***Operating a Vacuum Furnace Under Humid Conditions***
- ***Understanding PID Temperature Control in Operating a Vacuum Furnace***
- ***Understanding Power Losses in a Vacuum Furnace***
- ***Important Considerations When Purchasing a Vacuum Furnace***
- ***Considerations When Selecting a Vacuum Furnace Water Cooling System***
- ***Reducing Energy Consumption When Operating a Vacuum Furnace***
- ***Explaining Vacuum and Vacuum Instrumentation***
- ***Understanding Emissivity and the Use of Thermocouple Test Blocks in a Vacuum Furnace***
- ***Vacuum Gauge Correction Factors***
- ***Leak Detection and Checking of Vacuum furnaces***
- ***Critical Areas of Preventive Maintenance***
- ***Evaluating Pan versus Rayon Graphite Felt Insulation for Vacuum Furnaces***
- ***The Use of a Residual Gas Analyzer (RGA) to Determine Differences in Graphite and All-metal Hot Zone Vacuum Operation (To be published)***