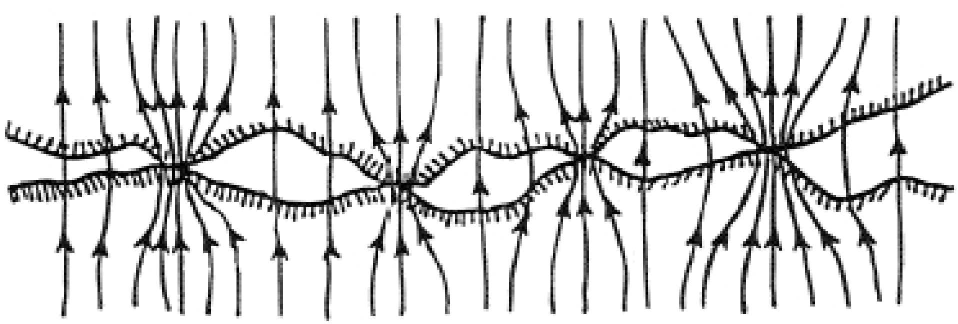
EMRP SIB 52 THERMO

Effect of surface thermal contact resistance (TCR) on thermal conductivity measurements of rigid insulation materials



Final meeting
NPL – May 2016

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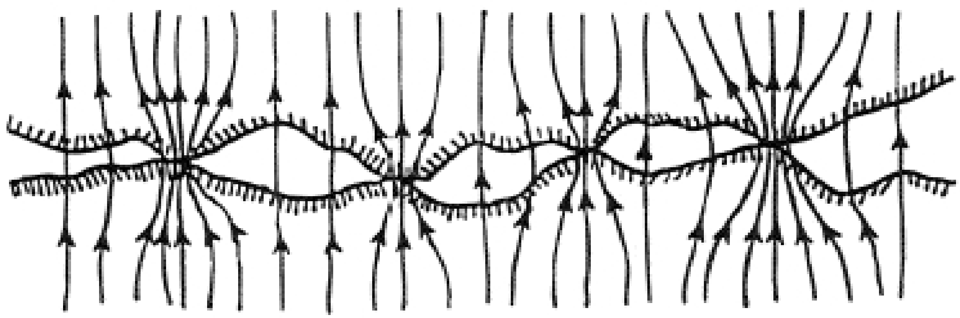
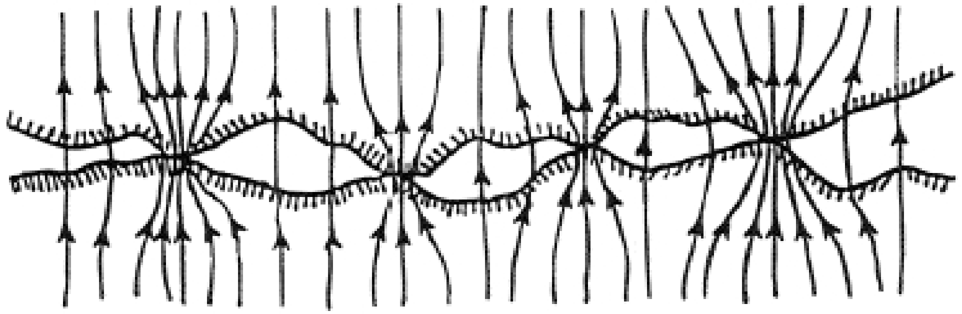


- When a junction is formed by pressing two similar or dissimilar solid materials together, only a small fraction of the nominal surface area is actually in contact because of the nonflatness and roughness of the contacting surfaces
- If a heat flux is imposed across the junction, the uniform flow of heat is restricted to conduction through the contact spots
- The limited number and size of the contact spots results in an actual contact area which is significantly smaller than the apparent contact area
- This limited contact area causes a thermal contact resistance

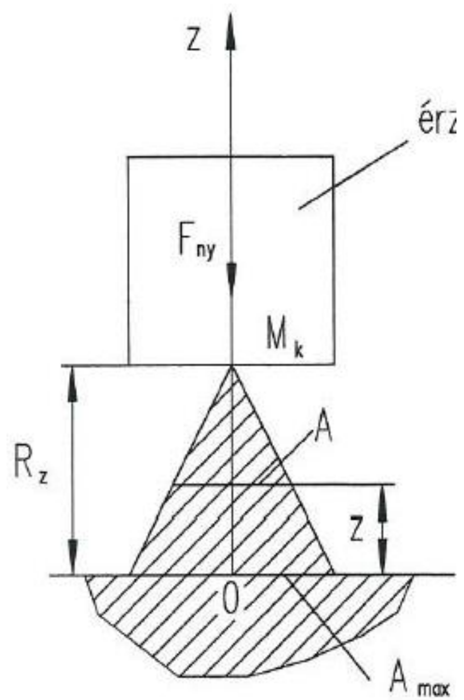


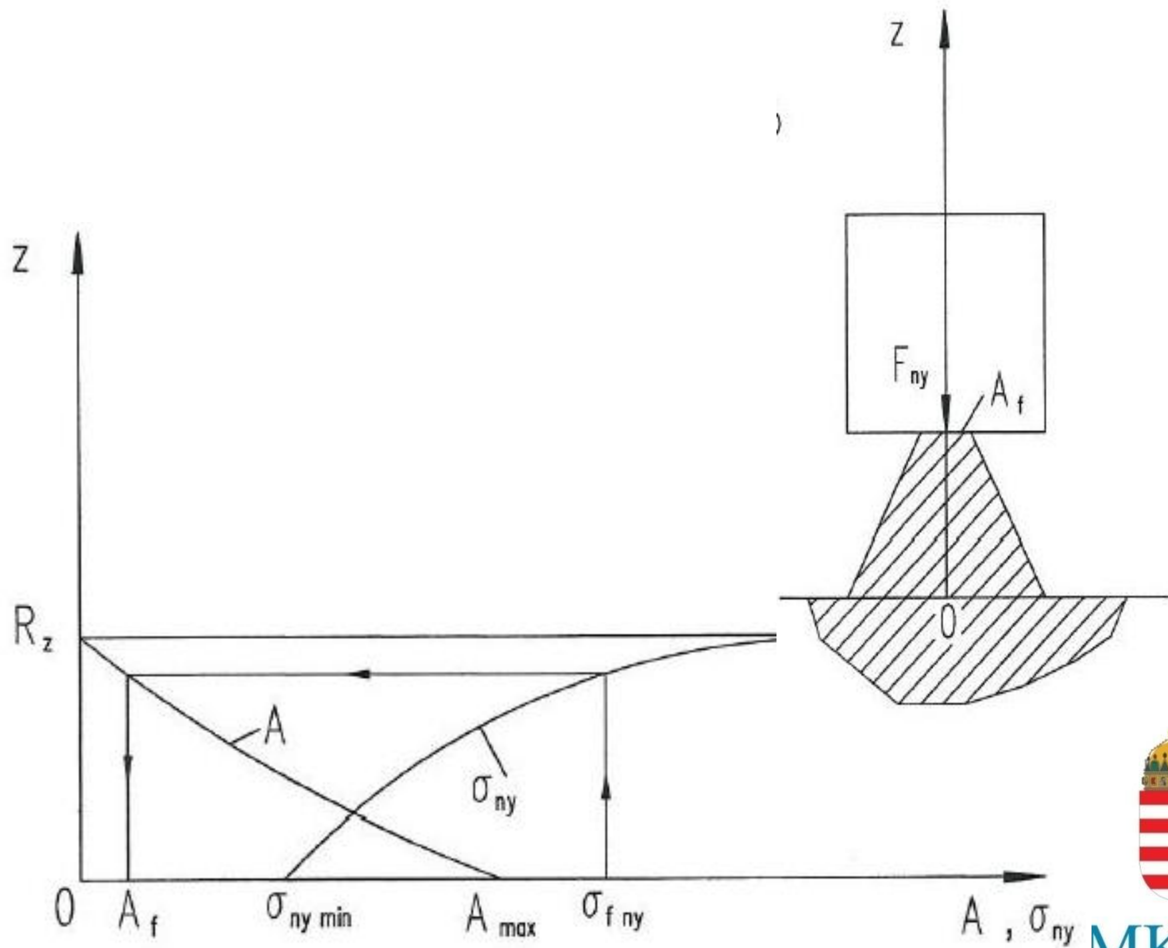
Heat transfer :

- by conduction
- by convection
- by radiation

- The ratio between the thickness of the air layer and the length of the contacting surfaces is small $\Rightarrow$ no convectiv heat flow without contact pressure

with contact pressure





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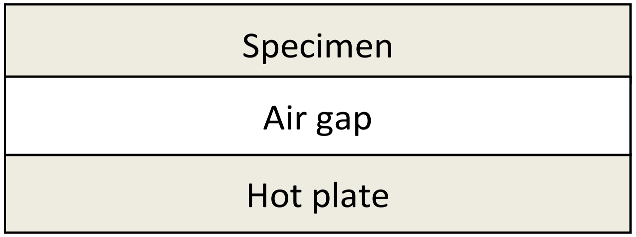
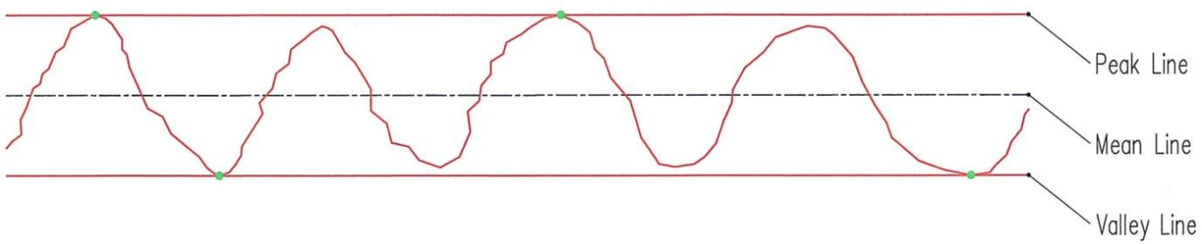
Dependence of the TCR on both flatness and roughness of the surfaces in contact

Flat surfaces



roughness



- There are only peaks in contact, but not all the peaks are in contact

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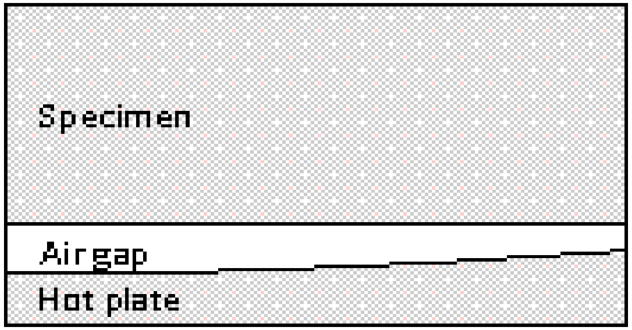
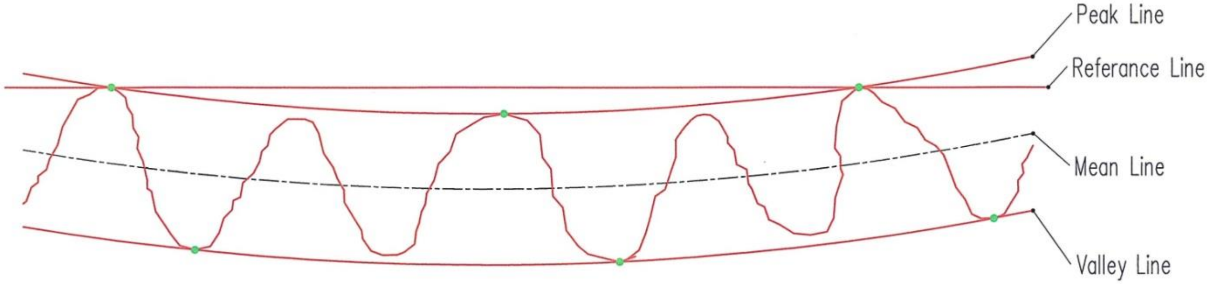
Dependence of the TCR on both flatness and roughness of the surfaces in contact

Nonflat surfaces





Roughness + Flatness

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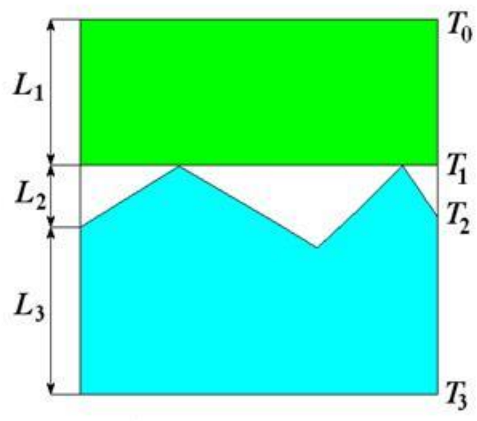
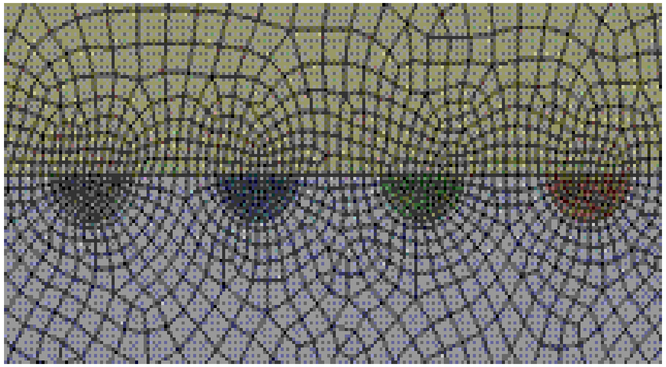
Dependence of the TCR
on both flatness and roughness of the surfaces in contact

Surface profile



Only peaks in contact

Mesh



Big surfaces in contact given in the numerical model of CMI ⇒

⇒ too optimistic approach

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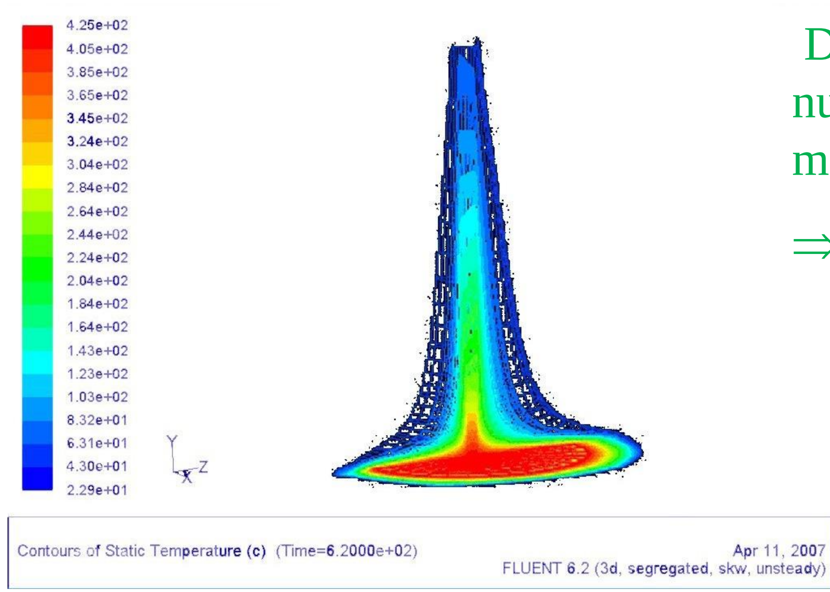
Validation of numerical models with experimental results

Example : temperature field in case of surface temperature measurement

FLUENT 3D *K-ω* model



Difference between numerical model and measurements : 27 %

⇒ should be validated

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Determination of the TCR

2 different ways in determination of TCR (R) :

$$R = \frac{d}{\lambda}$$

λ - thermal conductivity of the air

d - thickness of the air layer

- The thickness of the air layer depends on many factors as contact pressure, roughness, flatness of the surfaces in contact ⇒ difficult to determine

Determination of the TCR

2 different ways in determination of TCR (R) :

$$R = \frac{\Delta t}{q}$$

Δt - temperature difference of the surfaces in contact

q - density of heat flow rate which crossing this section

- If we can measure the temperatures of both surfaces in contact ⇒
  ⇒ this method is the most easy, precise and correct way to determine the magnitude of the TCR
- In this case the magnitude of the TCR doesn’t depend on the characteristics of the apparatus, as can be seen from the equation.

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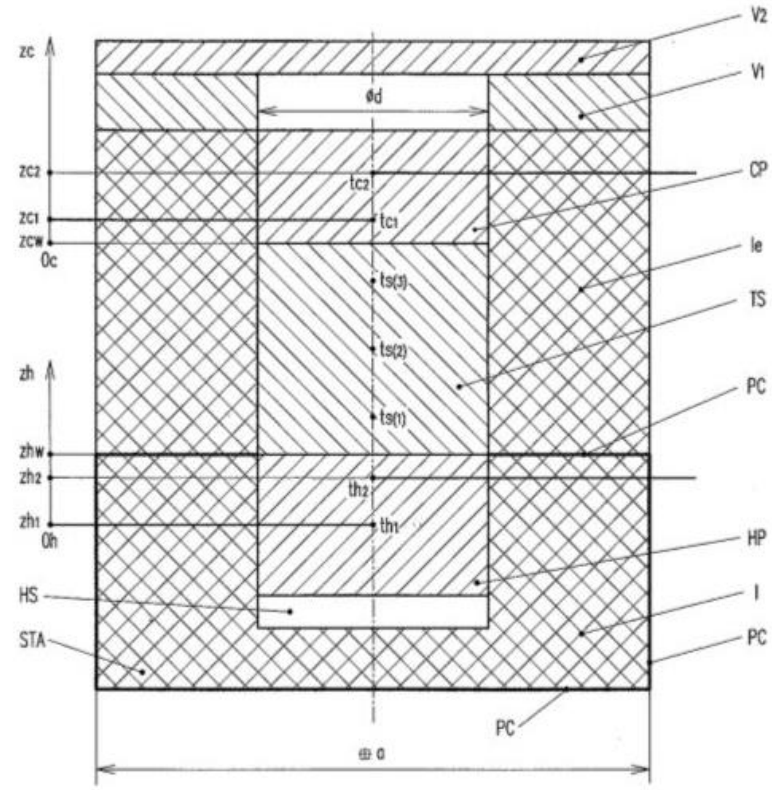
Determination of TCR at MKEH using two different experimental methods

Extrapolation method for temperature determination

- TCR arising between a rigid sample and the heated plate of a HTGHP can cause significant discrepancies in thermal conductivity measurements
- The developed set-up for modelling a GHP is compounded from heat source (HS), hot plate (HP), cold plate (CP), insulation (I) applied to prevent the heat loss in radial direction and protective cover (PC)
- Thin thermocouples are placed along the isotherm inside a solid body. Based on the indications of particular thermocouples, the surface temperature can be determined by extrapolation, without any deformation of the original surface temperature distribution



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Considering the measurement technique based on temperature sensors placed inside the hot and cold plate respectively :

- Extrapolated surface temperature of the HP and CP

$$thw = th1 - \frac{zhw - zh1}{zh2 - zh1} \cdot (th1 - th2)$$

$$tcw = tc2 - \frac{zc2 - zcw}{zc2 - zc1} \cdot (tc1 - tc2)$$

- Thermal conductivity of the specimen

$$\lambda w = \frac{\emptyset \cdot d}{A \cdot (thw - tcw)}$$

Considering the measurement technique based on temperature sensors placed inside the specimen :

- Thermal conductivity of the specimen

$$\lambda s = \frac{\emptyset \cdot d}{A \cdot (ths - tcs)}$$

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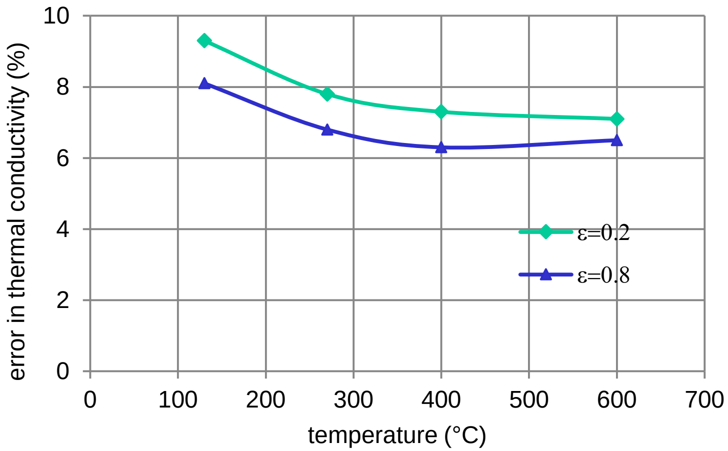
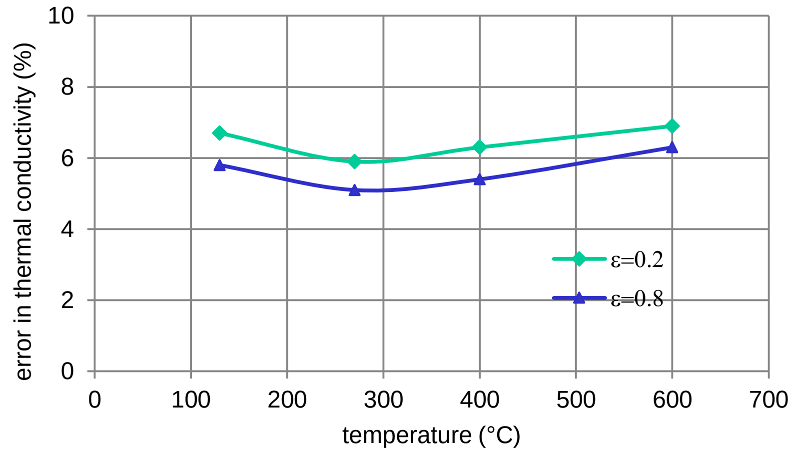
Errors of λ caused by TCR for LDCaSi specimens



Errors of λ caused by TCR for HDCaSi specimens



- Thermal conductivity measurements were effectuated using two types of test specimens
- The effect of the emissivity on the thermal contact resistance was studied changing the materials of the hot and cold plates having different emissivities

$$error(\lambda_{rel}) = \left(1 - \frac{\lambda s}{\lambda w}\right) \cdot 100$$

$$error(\lambda_{rel}) = \left(1 - \frac{thw - tcw}{ths - tcs}\right) \cdot 100$$

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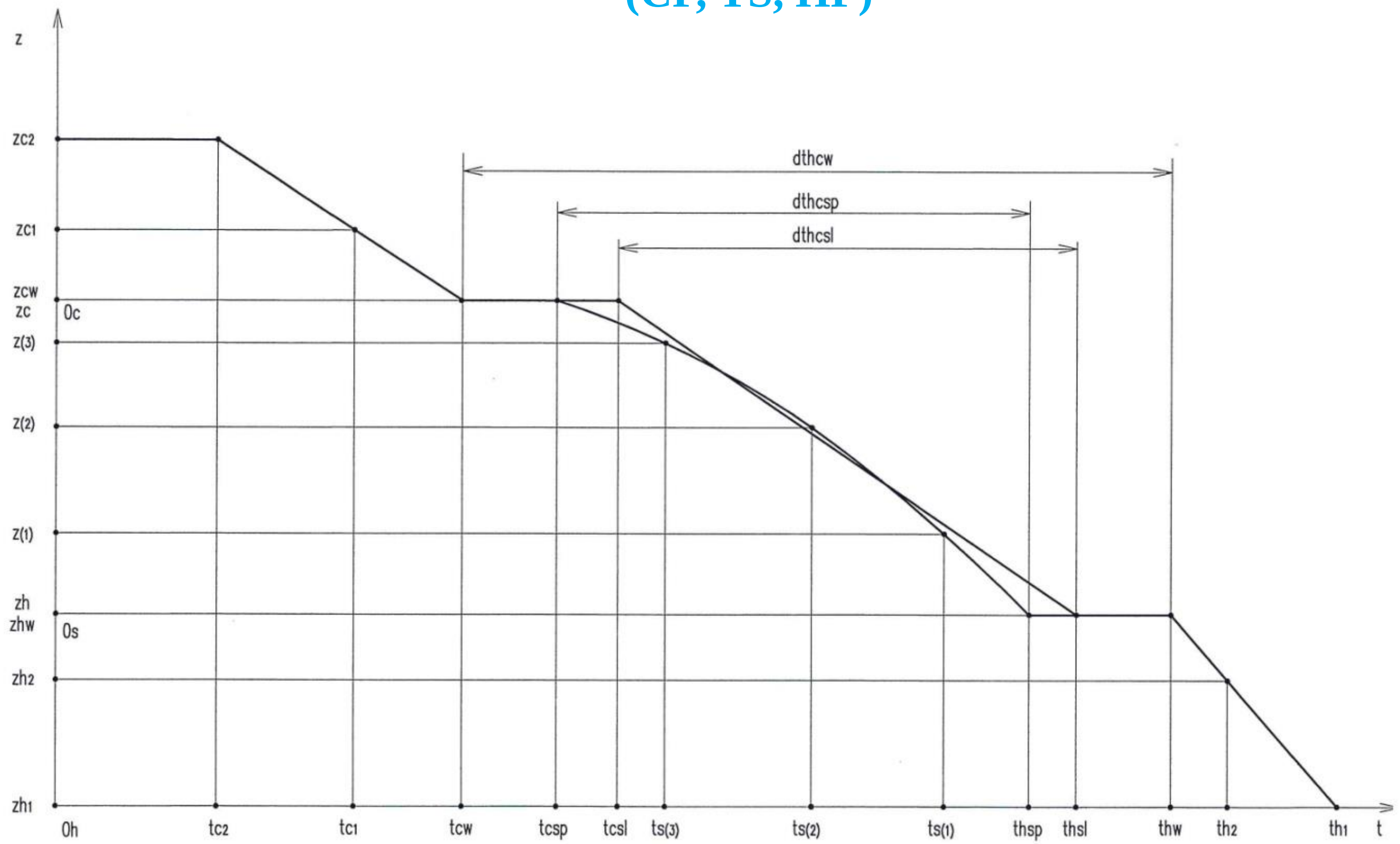
Temperature drop inside a GHP
(CP, TS, HP)



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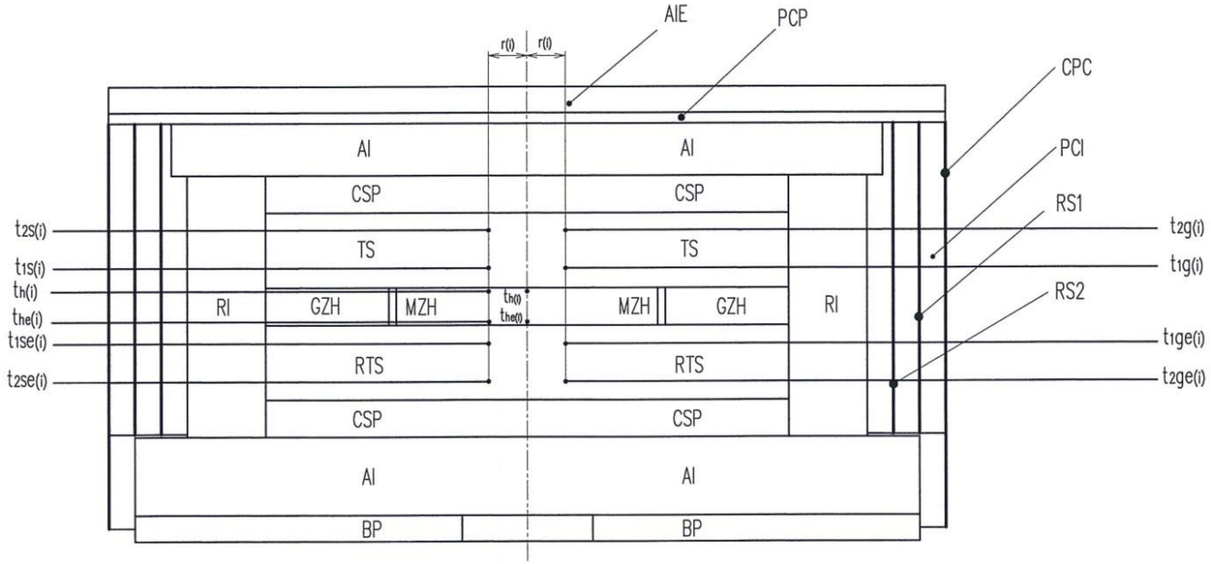
Determination of the TCR with the HTTCMA
MKEH HTTCMA suitable for determination of TCR arising between specimen and heater plate



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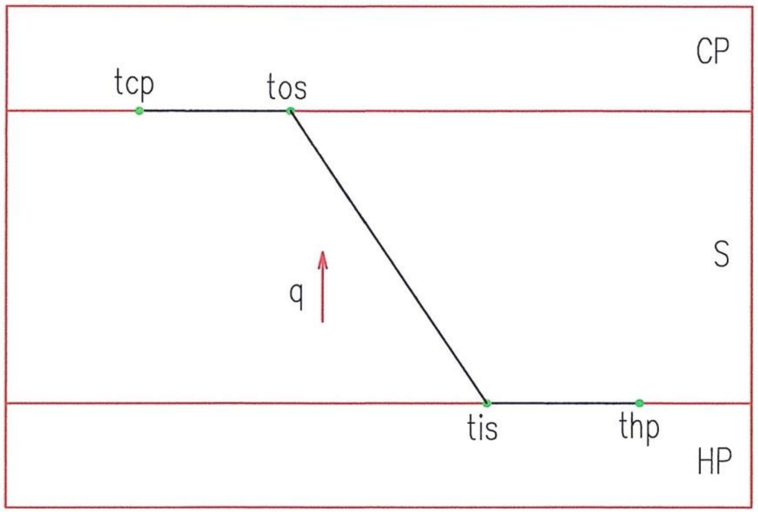
Determination of the TCR with the HTTCMA



HP - Hot Plate
CP - Cold Plate
S - Specimen
t_{hp} - Temperature of the HP surface
t_{cp} - Temperature of the CP surface
t_{is} - Temperature of the S inlet section
t_{os} - Temperature of the S outlet section
q - Density of heat flow rate
Ri - TCR at inlet section
Ro - TCR at outlet section

$$t_{hp} - t_{is} = R_i \cdot q \qquad t_{is} = t_{hp} - R_i \cdot q$$

$$t_{os} - t_{cp} = R_o \cdot q \qquad t_{os} = t_{cp} - R_o \cdot q$$

$$t_{is} - t_{os} = t_{hp} - t_{cp} - (R_i + R_o) \cdot q$$

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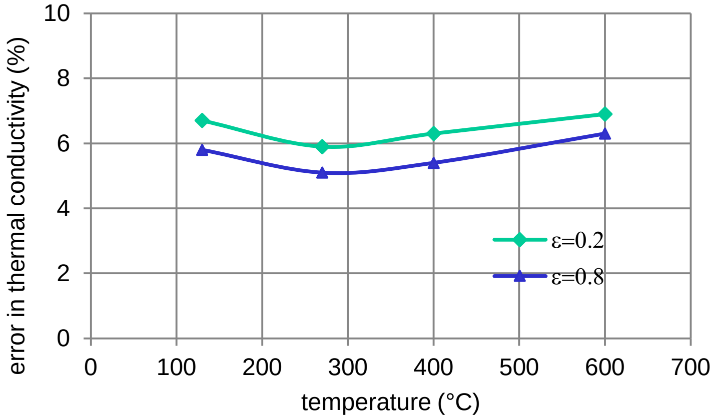
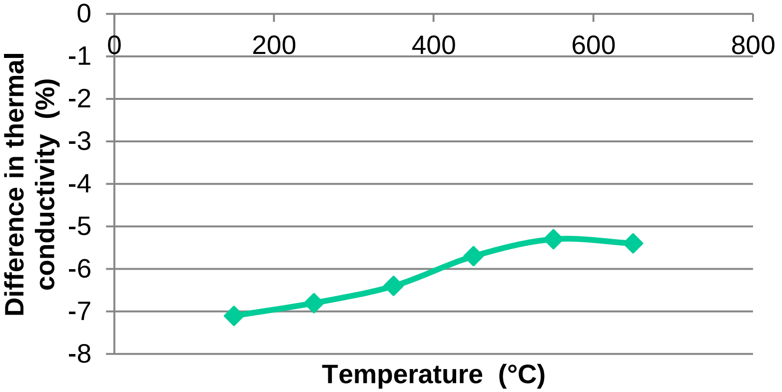
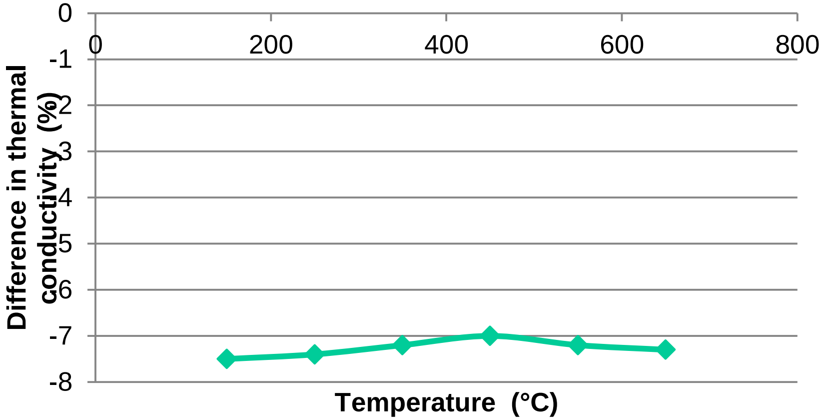
TCR - agreement between the different measurement methods

Measurements with
Ref. Surface App.



Measurements with HTTCMA





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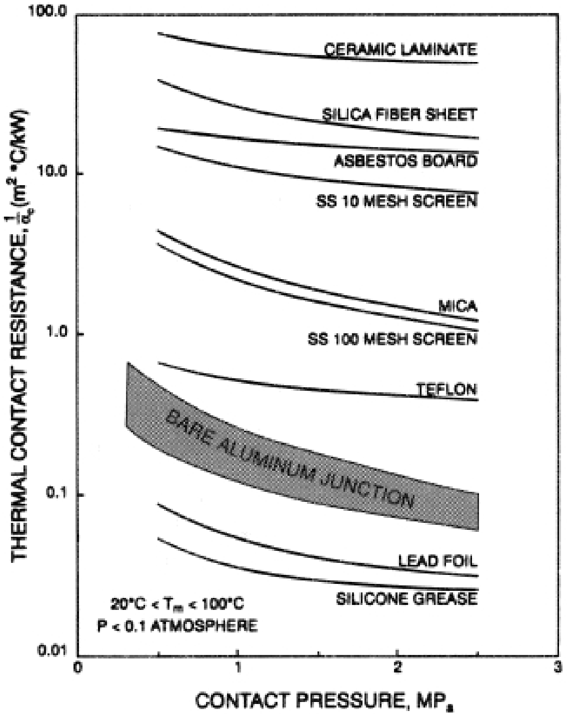
TCR - agreement between measurement values given in the scientific literature and those obtained with the HTTCMA



- TCR given in the scientific literature :
- for metals:
  from 0.1 to 1 (m^2 °C/kW)
- for rigid isolation materials:
  from 10 to 100 (m^2 °C/kW)
- Measured with HTTCMA :
  ~ 13 (m^2 °C/kW)

Increase of error in λ if temperature drop of the specimen is small

- L. S. Fletcher, A1AA Journal of Spacecraft and Rockets, 9, 12, 849-850. DOI: 10.2514/3.61809 (1972)
- www.thermopedia.com/content/1188

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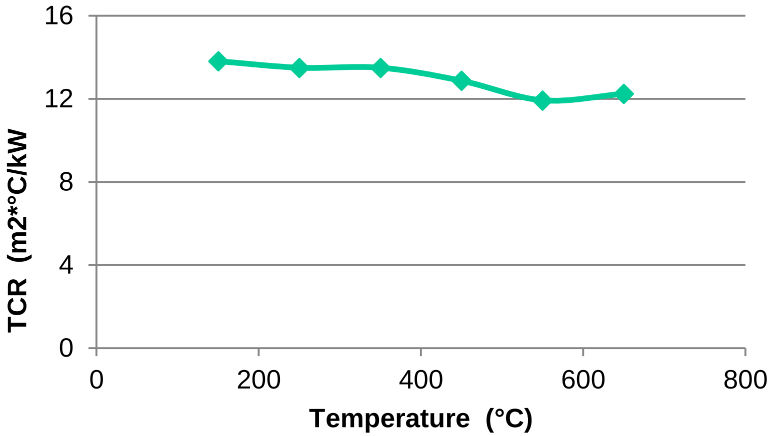
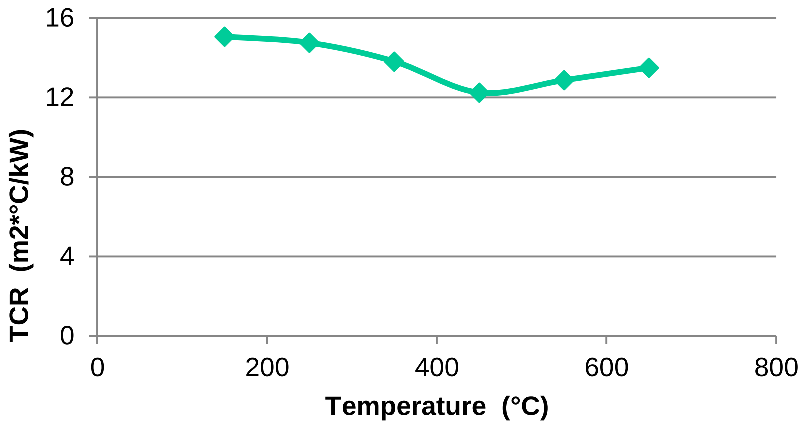
Examples of TCRs for the surfaces in contact in case of the HTTCMA





- The experimental results show that the magnitude of TCR doesn't depend on the mean temperature of the specimen.

  Both the Δt and q is changing and their ratio is approximately constant.

$$R = \frac{\Delta t}{q}$$

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Examples of TCRs in case of HTGHPs

$$R = \frac{\Delta t}{q}$$

- In case of a given mean temperature of the specimen $\Rightarrow$ q = const. $\Rightarrow$
  $\Rightarrow$ the TCR (R) strongly depends on Δt

Example :

0.1 / 216 = 0.000469 (m^2°C/W)
0.5 / 216 = 0.000231 (m^2°C/W)
1.0 / 216 = 0.000469 (m^2°C/W)

$\Rightarrow$ The numerical model which gives that R doesn't depend on Δt is not correct.

Difference in thermal conductivity measurements between the MKEH HFM and the MKEH HTTCMA due to TCR

- HFM validated in EURAMET Pr 426
- Temperature range :

  from 50 to 200 °C
- HDCaSi specimen from the SS protocol
- Lower thermal conductivity of around 5% due to TCR

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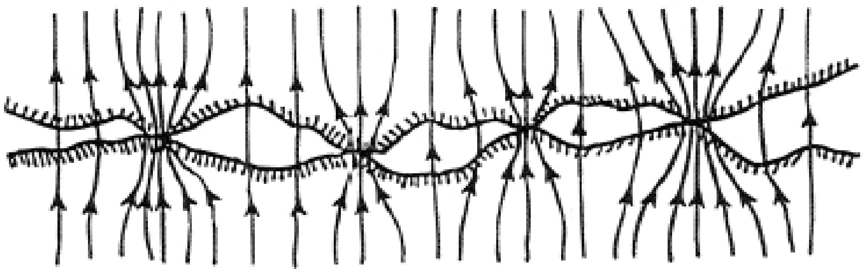
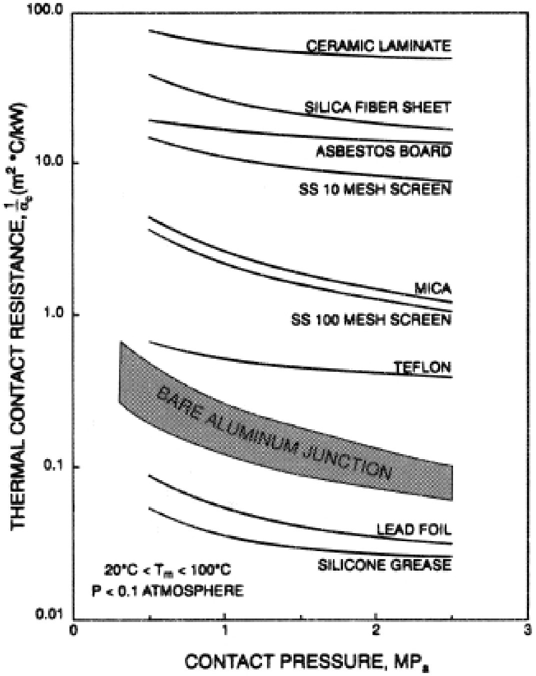
Effect of surface thermal contact resistance (TCR) on thermal conductivity measurements of rigid insulation materials

If the temperature is measured in HP and CP respectively, and if the TCR has high influence and is not quantified, this means that there is not enough information about the temperature of the specimen.

In this case can’t be proved that the heat flow in the specimen is unidirectional.





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Effect of surface thermal contact resistance (TCR) on thermal conductivity measurements of rigid insulation materials

Usually the thermal conductivity of isolation materials is not constant for such a wide temperature range (even 12% difference).

The thermal conductivity for this type of HDCaSi is decreasing until 500°C.

Pyrotek NAD-1000 High Temperature Engineering Board

Categories: Ceramic

Material Notes: NAD-1000 is a high density calcium silicate board reinforced with selected fibers to produce excellent thermal characteristics and dimensional stability up to 1000°C. NAD-1000 retains high strength after thermal cycling and has good impact resistance.

Thermal Conductivity	0.290 W/m-K @Temperature 538 °C	2.01 BTU-in/hr-ft²-°F @Temperature 1000 °F
	0.310 W/m-K @Temperature 204 °C	2.15 BTU-in/hr-ft²-°F @Temperature 399 °F
	0.330 W/m-K @Temperature 870 °C	2.29 BTU-in/hr-ft²-°F @Temperature 1600 °F
Maximum Service Temperature,	1000 °C	1830 °F