# INTER-LABORATORY TEST ON THERMOPHYSICAL PROPERTIES OF THE ITER GRADE HEAT SINK MATERIAL COPPER-CHROMIUM-ZIRCONIUM

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## Motivation – Material

- Determine quality and comparability and enhance the reliability of thermophysical property measurements
  → pre-requisite for high-quality standard material development within the ExtreMat project
- Determine confidence ranges for the thermophysical properties of Copper-chromium-zirconium

commercially available alloy; precipitation-strengthened; composition conforms to DIN 17666

several names: Cu-Cr-Zr (Zollern), C18150 (Ampco Metals, Inc.), ELBRODUR® (KME-Ag), MATTHEY 328 (Johnson Matthey Metals), and YZC (Yamaha Co, LTD).

The heat sink material is used in high heat flux components in actual and future fusion facilities, e.g. JET, ITER due to its good thermal conductivity and mechanical strength at low and moderate temperatures. However, aging at T > 500 C results in limited operational temperature.

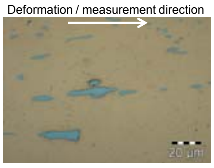


*Fig.2: Microstructure of CuCrZr with deformed Cr-precipitations along the longitudinal axis of the CuCrZr-bar*

Investigated material grade

- bar material (35 x 35 x 1000 mm³) produced by the company Zollern
- production: solution annealing at 970°C for 20 min → water quenching and aging at 475°C for 2 hrs
- composition: Cu-0.85Cr-0.09Zr
- thermal conductivity according to ITER properties handbook → lowest among all CuCrZr grades reported in literature (see *Fig. 1*)
- material inhomogeneities due to fabrication process → defined orientation of investigated specimens (see *Fig.2*)

Defined measurement parameters

- surface treatment, temperature range (RT to 500 C), atmospheric condition, data acquisition and repetition rate (≥ 2 cycles)

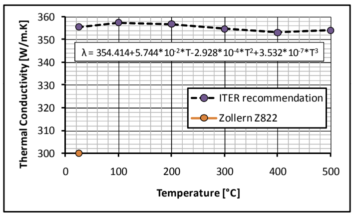


*Fig.1: Thermal conductivity for CuCrZr according to the ITER recommendation (equation valid for T ≤ 500 C) and the literature value for the Zollern material;*

## CTE – Density

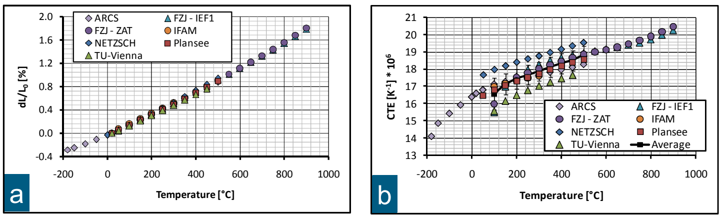


*Fig.3: Results from push-rod dilatometry vs. temperature: a) relative elongation; b) coefficient of thermal expansion with average and standard deviation between 100 C and 500 C*

Push-rod dilatometry

- supply of $dL/L_0$-curves – determination of the technical CTE with $T_0$ = 20°C
- results (see *Fig.3*) independent on number of specimens (≤ 3 per partner) and cyclic measurement
- low temperature measurements starting from -180°C (ARCS) → increase in reliability of RT-measurements
- high temperature measurements up to 900°C (FZJ) → independence of CTE on material aging
- average & standard deviation (68%) between 100°C and 500°C
- Δ $(CTE)_{max,min}$ at 100°C: ~15% (~2.5 $K^{-1}$ * $10^6$)
  at 450°C: ~9% (~1.7 $K^{-1}$ * $10^6$)

Density

CTE → volumetric expansion → decrease of density as a function of temperature (see Fig.4)

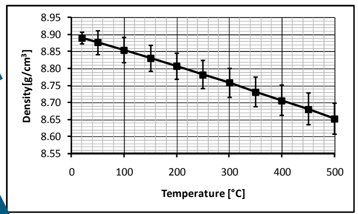


*Fig.4: Density as a function of temperature; measurement at RT, calculation at T > RT*

## Thermal Conductivity

- calculation of the thermal conductivity from density, specific heat and thermal diffusivity by using the equation **λ = ρ•$c_p$•a**
- thermal conductivity for the given thermal diffusivity values of the „Arbeitskreis Thermophysik" calculated using herein measured specific heat and density
- determination of the standard deviation by taking propagation of uncertainties into account

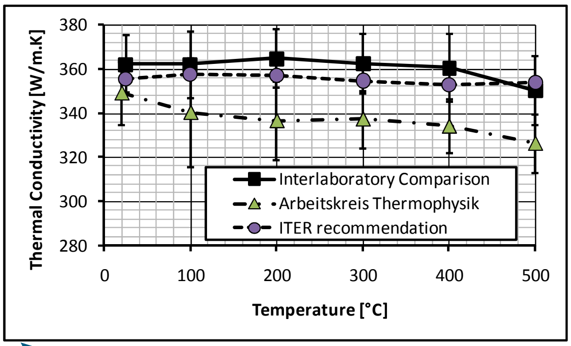


*Fig.9: Calculation of thermal conductivity: comparison of IC-average, AK-average and ITER recommendation between RT and 500 C*

**Conclusion**

- Good agreement of the different laboratory data → highest deviation for the thermal diffusivity measurements
- Thermal conductivity for CuCrZr produced by Zollern significantly higher than given in literature and corresponding to the ITER recommendation despite high temperature tendency: decrease instead of increase!
- Comparison between the two studies on CuCrZr shows a deviation of the average of ~7 % - disagreement becomes larger at higher temperatures due to smaller standard deviations

## Thermal Diffusivity

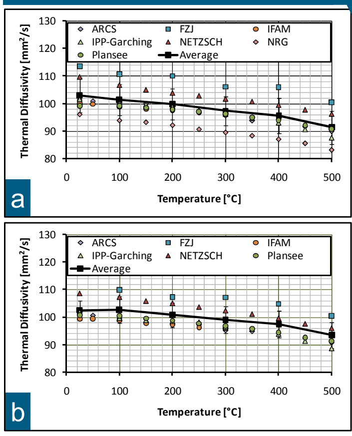


*Fig.7: Thermal diffusivity measured by LFA, average and standard deviation between RT and 500 C; a) first cycle; b) second cycle: no data from NRG! → higher average*

Laser Flash Apparatus (LFA)

- maximum of 2 representative specimens
- values for Plansee taken from 3 mm specimens
- separation of first and second cycle (see *Fig. 7* and *Fig. 8a*)
- laser voltage from 8.5 to 1750 V (IFAM: Nanoflash)
- evaluation model: Cowan + pulse length correction
- measurement uncertainties: 3 - 5 %
- comparison with a study on the same material within the "Arbeitskreis Thermophysik" (see *Fig.8b*)

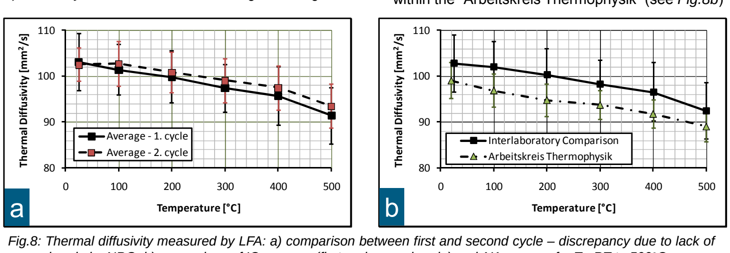


*Fig.8: Thermal diffusivity measured by LFA: a) comparison between first and second cycle – discrepancy due to lack of second cycle by NRG; b) comparison of IC-average (first and second cycle) and AK-average for T =RT to 500°C*

## Specific Heat

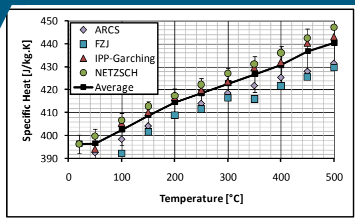


*Fig.5: Specific heat measured by DSC; average and standard deviation between 50 C and 500 C*

Differential Scanning Calorimetry (DSC)

- no influence of thermal cycling
- slight variation in specific heat between the single specimens per lab
- Δ $(c_p)_{max,min}$ between 2 and 4%; measurement uncertainties: 3 % (NETZSCH), 5 % (rest)
- average and standard deviation from 50°C to 500°C
- different slopes of NETZSCH/IPP-Garching and ARCS/FZJ for T ≥ 300°C

Specific Heat by Laser Flash Apparatus (LFA)

- measurements performed at Plansee on 3 and 5 mm thick LFA -specimens
- 5 mm specimens: steady increase from cycle to cycle → steady state after the sixth cycle (see *Fig.6a*)
- 3 mm specimens: measurement data within the standard deviation of the DSC measurement (see *Fig.6b*)
- average for 5 mm specimens in *Fig.6b* done on 3 specimens and 3 cycles each; Δ$(c_p)_{3mm,5mm}$ ≈ 22 J/kg.K

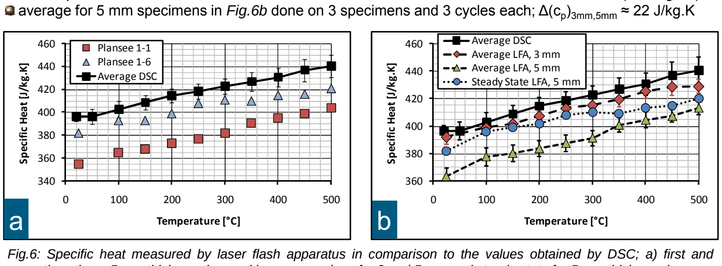


*Fig.6: Specific heat measured by laser flash apparatus in comparison to the values obtained by DSC; a) first and seventh cycle on 5 mm thick specimens; b) average values for 3 and 5 mm and steady state for 5 mm thick specimens*



ExtreMat

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SIXTH FRAMEWORK PROGRAMME