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# Thermophysical properties of the Ni-based alloy Nimonic 80A up to 2400 K, III

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**Abstract**

Nimonic 80A is a nickel–chromium alloy which is strengthened by additions of titanium and aluminum. The alloy is used for high temperature, high-strength applications. This superalloy is used in gas turbine hot section components, for hot-working applications and forging hammers.

This is the third paper reporting thermophysical properties of Nimonic 80A. The optical measurement of temperature is limited by our fast pyrometers with $T_{min} = 1200$ K for this material and data above about 1200 K have been reported in the previous papers [1,2].

Specific heat capacity data from 500 K up to 1500 K obtained by direct measurement using a differential scanning calorimeter have been used to compute enthalpy as function of temperature.

By combining pulse heating and DSC measurements now it is possible to assign a temperature to electrical resistivity and thermal conductivity in the observed temperature range. Thermal conductivity is estimated using the Wiedemann–Franz law.

The investigated specific heat capacity, enthalpy, resistivity and thermal conductivity data as function of temperature are presented and compared to literature-values.


*Keywords:* Thermophysical properties; Nimonic 80A; Resistivity; Enthalpy; Heat capacity; Thermal conductivity; Thermal diffusivity

## 1. Introduction

Several thermophysical data for the solid and liquid material have been measured and presented for temperatures above 1100 K in previous papers [1,2]

Within this paper new calorimetric measurements are presented and combined with pulse heating data, where no signal was available from the pyrometer used for the optical temperature measurement.

Data in the solid phase of Nimonic 80A are discussed and compared to literature data, if available. Table 1 gives an overview of the properties of the measured alloy —a typical chemical composition, liquidus temperature, and solidus temperature as specified by Böhler Edelstahl GmbH. The density $d$ at room temperature was determined by turning a cylinder with maximum machine accuracy with the dimensions of about 50 mm in diameter and 50 mm height, measuring and weighing it.

## 2. Experimental method

To perform accurate specific heat capacity ($c_p$) measurements of our samples a differential scanning calorimeter (DSC) Netzsch DSC 404 was used for obtaining data in the temperature range of about 500–1500 K. The calculated specific enthalpy $H$ is set to zero at room temperature, 298 K. From the first datapoint to room temperature the $c_p$ value is extrapolated from a linear fit of the mean value of the $c_p$-data of the first and second run in the temperature range of 480–800 K.

For all of the four different samples with a mass between 109.9 and 173.3 mg a heating rate of 20 K min$^{-1}$ and a sapphire standard was used.

All electrical data presented in this work are obtained by the means of a fast pulse heating technique which is described

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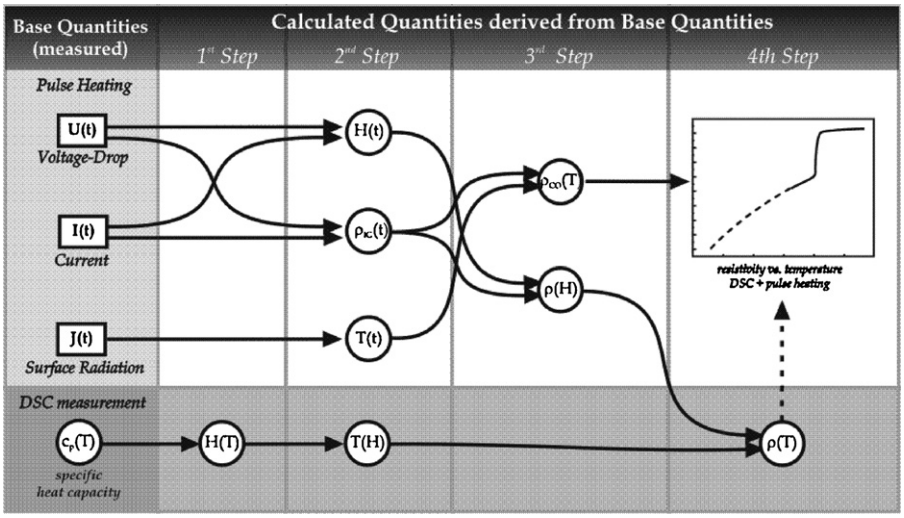


Fig. 1. Schematic overview how pulse heating data are combined to DSC data.

detailed in Refs. [3–5]. Within this setup a time-dependent temperature measurement is performed with a spectral pyrometer developed at the Institute of Experimental Physics (Graz University of Technology) at a wavelength of 1570 nm and a bandwidth (FWHM) of 84 nm. Due to the lack of intensity at low temperatures the working temperature for this pyrometer starts at about 1250 K.

Below this temperature only electrical data namely current, voltage from the pulse heating experiments are used to determine electrical resistivity $\rho$ as function of specific enthalpy.

Incorporating the relation of enthalpy – temperature measured by the DSC – it is possible to assign a temperature to the resistivity data via specific enthalpy. A short overview of the calculated quantities derived from base quantities is given in Fig. 1.

To compensate the volume expansion of the sample in the low temperature range an interpolation of the polynomial fit (Eq. (1)) of density $d$ (kg m$^{-3}$) versus temperature $T$(K) between room temperature and the first datapoint at 1100 K is used from the data already published [2].

$$\mathrm{d}(T) = 8251.0 + 1.01 \times 10^{-2} T - 2.845 \times 10^{-4} T^2 \quad 1100\,\mathrm{K} < T < 1593\,\mathrm{K} \tag{1}$$

Thermal conductivity $\lambda$ is estimated via the Wiedemann–Franz law (Eq. (2)) which states that the ratio of the thermal conductivity to the electrical conductivity $1/\rho$ of a metal is proportional to the temperature:

$$\lambda(T) = \frac{LT}{\rho(T)} \tag{2}$$

where $L$ is the Lorentz number, $L = 2.45 \times 10^{-8}\,\mathrm{V^2\,K^{-2}}$ [3], assuming that the Lorentz number is invariant within the region of interest.

Table 1
Material properties of Nimonic 80A

| | |
|---|---|
| Name | Nimonic 80A |
| Composition | Ni, balance; Cr, 19.5%; Ti, 2.5%; Al, 1.7%; Fe, max. 1.5% |
| $T_{solid}$ (K) | 1593 |
| $T_{liquid}$ (K) | 1638 |
| Density, 20 °C (kg m$^{-3}$) | 8152 |

## 3. Results und discussion

Curves obtained for the apparent specific heat capacity ($c_p$) from the DSC measurement at two identical temperature profiles are illustrated in Fig. 2 in the temperature range 500 K < $T$ < 1500 K. According to the definition of specific heat capacity, where contributions from phase transitions are not included, the given data include all these deviations. All marked

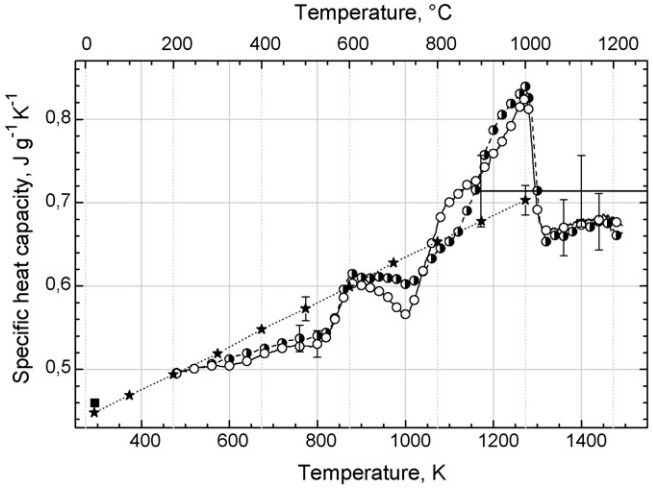


Fig. 2. Specific heat capacity from DSC measurements. (open circles) First run; (half filled circles) second run; (full line) $c_p$ from slope of $H(T)$ by pulse heating; (connected stars) calculated values from Betteridge and Heslop [6]; (full square) single value at room temperature from ASM Handbook [7].