Solidus and Liquidus Temperatures of Zr-1% Nb

Preliminary Recommendation

The recommended values for the solidus and liquidus temperatures of Zr-1%Nb are:

$$\text{SolidusTemperature} = 2100\text{K}$$

$$\text{LiquidusTemperature} = 2110\text{K}$$

These values are from subsecond heating measurements of the solidus temperature and the indirect determination the liquidus temperature of Zr-1%Nb reported by Peletsky and Petrova in 1997 [1]. The solidus temperature is identical with that recommended in the IBRAE Material Property Database on the world wide web and in the Russian Academy of Sciences Nuclear Safety Institute (IBRAE) report by Ozrin et al. [2]. The liquidus temperature differs by 1K from the 2109 K value reported in a 1995 paper by the same authors [3] and recommended in the IBRAE database and the report by Ozrin et al. [2]. The values based on the most recent analysis of their experimental data are preferred.

Uncertainty

Because no other measurements of the solidus and liquidus temperatures of this alloy are available in the literature, Peletsky and Petrova compared their temperatures with values obtained from the recent Zr-Nb phase diagram of Guillermet [4] that was based on experimental data for Zr-Nb alloys with niobium content greater than 5%. The solidus and liquidus temperatures of Zr 1% Nb obtained from the phase diagram are 2112 and 2119 K, respectively. These values differ by only 0.5% from the values obtained from the experiments of Peletsky and Petrova. The largest uncertainty in the determination of the liquidus temperature arises from the uncertainty in the enthalpy of fusion because older measurements of the enthalpy of fusion of zirconium gave values ($\sim 230\ J \cdot g^{-1}$) that are approximately 60% higher than the value used by Peletsky and Petrova. However, use of the higher values for the enthalpy of fusion would have given an increase that is less than the 2119 K value given in the phase diagram. Thus, the uncertainty in the recommended solidus and liquidus temperatures of Zr-1%Nb may be assumed to be less than 1%.

Discussion

Peletsky and Petrova [1] measured the solidus temperature with a pyrometer focused on a black-body hole in Zr-1%Nb samples during subsecond heating experiments. The beginning of melting was determined by the sharp reduction of temperature caused by the presence of a liquid phase on the internal surface of the black body hole. At the instant of appearance of a liquid phase, there is a change in the reflectance and reduction of the effective emissivity of the black body. This moment in time also corresponds to the start of a plateau in a plot of brightness temperature as a function of time. The reported solidus temperature, 2100 K, is the mean value of the measured solidus temperatures.

The liquidus temperature was calculated from an indirect procedure because the samples collapsed prior to completion of melting. Peletsky and Petrova assumed that the enthalpy of fusion of Zr-1%Nb alloy is equal to the enthalpy of fusion of pure zirconium and that the increase in temperature during melting is proportional to the enthalpy of fusion. In their calculations, they used an enthalpy of fusion of 140 $J \cdot g^{-1}$, the enthalpy of fusion of zirconium obtained from the recent measurements by Korobenko and Savvatimsky [5]. At the time the sample collapsed, the increase in the enthalpy from the enthalpy at the solidus temperature was 33% of the enthalpy of fusion of zirconium. During this same time, the brightness temperature had increased 3 K. From the assumption that the increase in temperature is proportional to the increase in enthalpy, they calculated a 9 K increase in the brightness temperature and a 10 K increase in the true temperature of the sample during melting. Thus, they determined the liquidus temperature of Zr-1%Nb to be 2110 K.

References

1. V. E. Peletsky, and I. I. Petrova, *Investigation of the thermophysical properties of the alloy Zr-0.01Nb by a subsecond pusle-heating technique*, High Temp.-High Pressures **29**, 373-378 (1997).

2. V. T. Ozrin, V. Yu Zitcerman, V. M. Gefter, and V. F. Bajbuz, *Material proeprties for International Nuclear Safety Data Base*, Russian Academy of Sciences Nuclear Safety Institute (IBRAE) report **NSI-SARR-34-96** (September 1996).

3. I. I. Petrova, and V. E. Peletsky, *Spectral (λ = 0.65 μ m) emissivity at the temperature of solidus Zr - 1% Nb alloy*, Teplofyz. Vys. Temp. **33,** (No. 5), 716-720 (1995) [in Russian]; High Temperature **33**, 710-714 (1995) [English translation].

4. A. F. Guillermet, Metallkunde **82**, 478-487 (1991).

5. V. N. Korobenko and A. I. Savvatimskii, *Properties of Solid and Liquid Zirconium*, Teplofiz. Vys. Temp. **29**, No. 5, 883-886 (1991) [in Russian], High Temperature **29**, 693-696 (1991) [English translation].

.