Journal of Thermal Analysis, Vol. 36 (1990) 433-439

THERMAL AND ELECTRICAL PROPERTIES OF DILUTE Cr-Ni BASE ALLOYS

A. S. A. Ammar, Ali M. Okaz, M. El-Osairy and *N. S. Mahmoud*

ENGINEERING PHYSICS AND MATHEMATICS DEPT. FACULTY OF ENGINEERING, ALEXANDRIA UNIVERSITY, ALEXANDRIA, EGYPT

(Received February 15,1989)

The ferro-paramagnetic phase transition in dilute Cr-Ni base alloys is investigated through a qualitative study of their thermal conductivity as a function of temperature in the near vicinity of the transition. A single apparatus was used to measure the thermal and electrical conductivities and the specific heat of three thin rod samples having Cr concentrations of 0.12, 0.51 and 1.13 at. %.

A voltage-temperature (V-θ) realign was applied to measure the ratio between the thermal and electrical conductivities. The thermal conductivity data were then evaluated by using the electrical resistivity results obtained from the measured current-voltage (I-V) characteristic curves. A model describing the effect of Cr concentration on the I-V curve is proposed and tested. The effect of Cr concentration on specific heat is also presented.

There have recently been several experimental and theoretical investigation on the nature of the magnetic phase transition in ferromagnetic metals and alloys. The study of transport properties such as electrical and thermal conductivities and thermoelectric power has a good deal of attention [1-5]. In the present work the ratio between thermal and electrical conductivities (K/σ) has been measured by the direct passage of an electric current through the specimen and by making use of V-θ relation.

The electrical resistivity (ρ) is evaluated directly from the *I-V* characteristic curves. The obtained data agree quite well with those determined previously for the same samples by using the four-probe method [4]. In order to understand the effect of Cr concentration on the *I-V* curve and consequently on the electrical resistivity, the following relation is proposed:

John Wiley & Sons, Limited, Chichester
Akadémiai Kiadó, Budapest

$$I = I_s \frac{aV}{1+aV}$$

where I_s is a saturation current and a is an impurity parameter which varies with the Cr concentration. The best values of I_s and a for pure Ni and each sample were calculated by using a chi-square (ψ^2) test and computer fitting.

Experimental

A detailed description of the apparatus was given in a previous publication [6]. The method is based upon a relation between the maximum temperature (Θ_m), at the centre of the sample, attained for a given current (I) and potential difference (V) between the ends of the specimen. For the specific heat measurements, homogeneous constant Joule heating is imposed on the sample. The initial rise in Θ_m was recorded as a function of time by using an X-Y recorder, which gives a straight line whose slope is inversely proportional to the heat capacity per unit volume, regardless of heat losses.

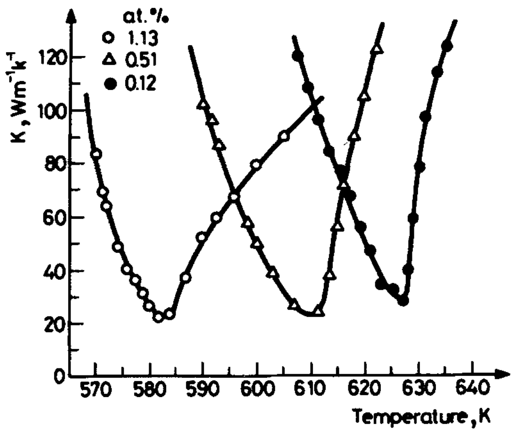

Fig. 1 Thermal conductivity K vs. temperature for three Ni-Cr alloys

The specimens used in this work are pure Ni an Ni base alloys with Cr concentrations of 0.12, 0.51 and 1.13 at. %, supplied by the Central Research Institute of Physics, Budapest, Hungary. They were prepared from high-purity starting metals by vacuum melting. The compositions of the alloys were determined by atomic absorption analysis. The dimensions of the sample Ni-Cr 0.12 at.%, were diameter = 2.6 mm, length = 5.1 cm.

Results and discussion

The thermal conductivity K as a function of temperature (T) is shown in Fig. 1 for the three samples. The Figure demonstrates that $K(T)$, for each sample, falls sharply with increasing T up to about the critical temperature T_c, where a rather sharp minimum is observed. This is in contrast with what was found for Ni-Mn alloys, where only a flat minimum was observed [3]. The reason for this minimum in $K(T)$ and the critical behaviour of the magnetic thermal resistivity have been discussed analytically for the case of pure Ni in a separate paper [7]. It can also be noticed from Fig. 1 that the critical temperature T_c decreases linearly with increasing Cr concentration, accompanied by the more pronounced rounding of the minimum in $K(T)$. This is in quite good agreement qualitatively with the electrical resistivity results [4], and quantitatively with the specific heat data [5] for the same samples.

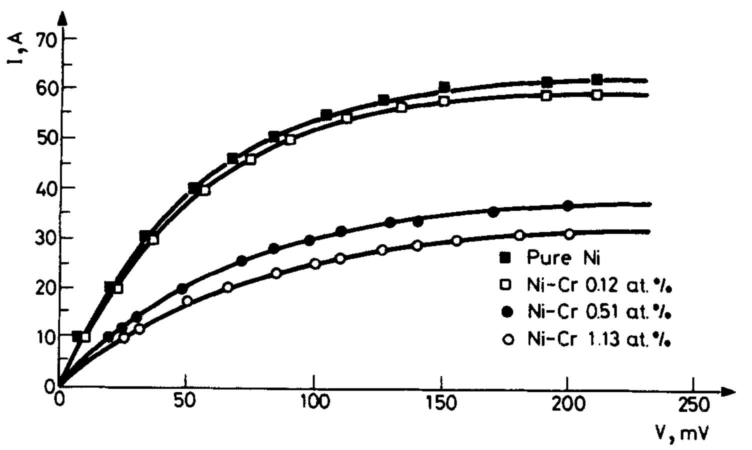

Fig. 2 Current - voltage curve for pure Ni and three Ni-Cr alloys

Table 1 Electrical resistivity as calculated from (I-V) curves for Ni-Cr 0.12 at. % sample compared with previously reported values [4]

T, K	$\rho\,(\Omega.m)\,10^8$, present	$\rho\,(\Omega.m)\,10^8$, previous [4]
610	24.04	23.88
612	24.14	24.02
614	24.22	24.16
616	24.33	24.32
618	24.41	24.44
620	24.54	24.62
622	24.67	24.77
624	24.77	24.91
626	24.89	25.10
628	25.06	25.27
630	25.20	25.42
632	25.27	25.49
634	25.35	25.56
636	25.41	25.63
638	25.57	25.72
640	25.64	25.81

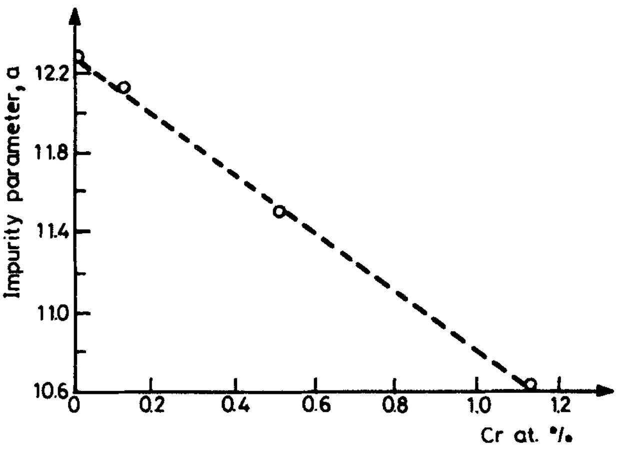

Fig. 3 Impurity parameter *vs.* Cr concentration

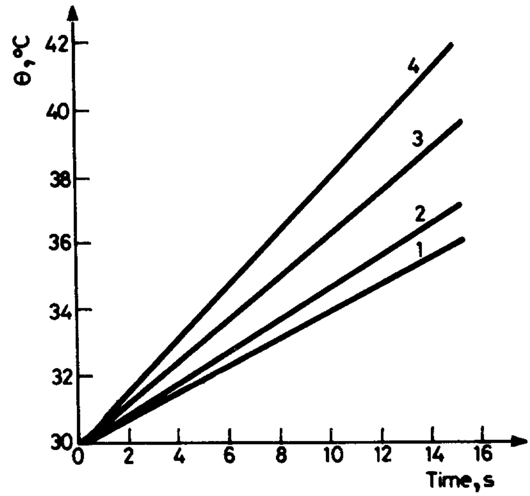

Fig. 4 Recorded temperature rise due to joule heating of the wire *vs.* time at 27°C. 1 - Pure Ni; 2 - Ni-Cr 0.12 at%; 3 - Ni-Cr 0.51 at.%; 4 - Ni-Cr 1.13 at.%

The electrical resistivity data, as calculated directly from the *I-V* characteristic curve in Fig. 2 and the sample dimensions, are given in Table 1, together with the previously reported results for the same samples [4]. Figure 3 gives the relation between the impurity parameter *a* and the Cr concentration for pure Ni and the three samples; it is found to be linear in this dilute concentration range.

Figure 4 gives the initial rise of temperature against time, for pure Ni and the three diluted samples, from which the specific heat data were calculated. Figure 5 gives the specific heat C_p as a function of the Cr concentration. It is clear that C_p increases with the concentration in a nearly parabolic way. Although this behaviour seems reasonable, a complete understanding is lacking.

As an attempt to understand the effect of Cr on the thermal conductivity behaviour, we have estimated first the non-magnetic contribution to the thermal conductivity (the linear part of K). This was taken to be the extrapolation of the thermal conductivity to the low-temperature range. We then subtracted this linear part (K_{lin}) from the total conductivity to get the magnetic part (K-K_{lin}).

Figure 6 shows the behaviour of (K-K_{lin}) *vs.* (T_c-T) in the ferromagnetic phase. The effect of Cr is not so severe in this dilute concentration range, as the magnetic contribution is nearly the same for these samples within the ex-

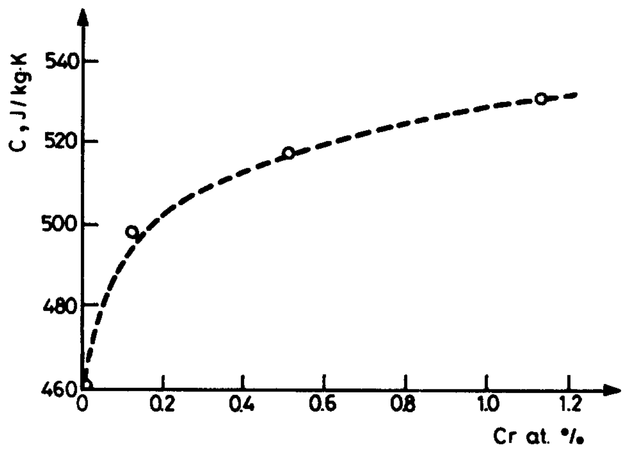

Fig. 5 Specific heat C *vs.* Cr concentration together with that of pure Ni

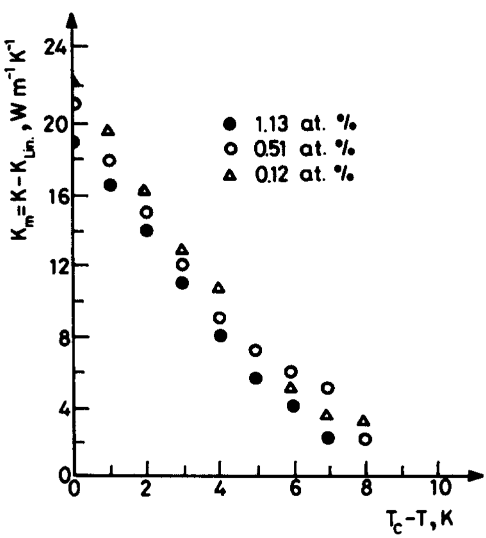

Fig. 6 Magnetic conductivity *vs.* temperature in the ferromagnetic phase

perimental uncertainty. Thus, it may be concluded that the strength of the spin – exchange interaction is probably equivalent in these dilute alloys [4, 7, 8].

References

1 P. J. Jackson and N. H. Saunders, Physics Letters, 28 A (1968) 19-20.
2 A. S. A. Ammar, Ali M. Okaz and Naim D. Tooma, Phase transitions, 1 (1980) 325-332.
3 J. B. Sousa, R. P. Pinto, M. M. Amado, M. F. Piheiro, J. M. Moreira and M. E. Braga, J. Physique, 41 (1980) 573.
4 A. S. A. Ammar, Ali M. Okaz, M. El-Osairy and A. Ghoneim, The Bulletin Fac. Eng. Alex. Univ., Vol XXII (1983) 25-41.
5 A. S. A. Ammar, Ali M. Okaz and M. El-Osairy, Indian J.Phys., 62A (1988) 365-373.
6 Ali M. Okaz, M. El-Osairy and N. S. Mahmoud, The Bulletin Fac. Eng. Alex Univ., Vol. XXV (1986) 101/120.
7 Ali M. Okaz, M. El-Osairy and N. S. Mahmoud, The Bulletin Fac. Eng. Alex. Univ., Vol XXVI (1987) 503-523.
8 M. Ausloos, Solid State Commun., 21 (1977) 273; J. Phys., All, (1978) 1621.

Zusammenfassung — Der ferro-paramagnetische Phasenübergang von gestreckten Cr-Ni Ausgangslegierungen wurde mittels einer qualititativen Untersuchung ihrer Wärmeleitfähigkeit als eine Funktion der Temperatur in nächster Nähe des Phasenüberganges untersucht. Mit Hilfe einer einzigen Apparatur wurden Wärme- und elektrische Leitfähigkeit sowie die spezifische Wärme von drei Probenstäben mit einem Cr-Gehalt von 0.12, 0.51 bzw. 1.13 % bestimmt.

Für die Ermittlung des Verhältnisses zwischen Wärme- und elektrischer Leitfähigkeit wurde eine Spannungs-Temperatur (V-Θ) Beziehung angewendet. Aus dem elektrischen Widerstand, erhalten aus den gemessenen Strom-Spannungskurven (I-V), kann dann die Wärmeleitfähigkeit ermittelt werden. Es wurde ein Modell entwickelt und getestet, um den Einfluß der Cr-Konzentration auf die (I-V)- Kurven wiederzugeben. Die Wirkung der Cr-Konzentration auf die spezifische Wärme wird ebenfalls beschrieben.