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THERMAL AND ELECTRICAL PROPERTIES OF DILUTE Cr–Ni BASE ALLOYS

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The ferro-paramagnetic phase transition in dilute Cr–Ni base alloys was investigated through a qualitative study of their thermal conductivity as a function of temperature in the near vicinity of the transition. A single apparatus [1] was used for measurements of the thermal and electrical conductivities and specific heats of three thin rod samples having Cr concentrations of 0.12, 0.51 and 1.13 at.%.

A voltage *vs.* temperature (V *vs.* θ) relation was applied [2] 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 *vs.* voltage (I *vs.* V) characteristic curves. A model describing the effect of Cr concentration on the (I *vs.* V) curve wasproposed and tested. The effect of Cr concentration on specific heat is presented.

Several recent experimental and theoretical investigations were concerned with 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 received a good deal of attention [1–5]. In the present work, the ratio between thermal and electrical conductivities, K/σ, was measured by the direct passage of an electric current through the specimen and by making use of the V *vs.* θ relation.

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

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

where I_s is a saturation current and a is an impurity parameter which varies with 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 a computer fitting.

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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 sample centre, attained for a given current, I, and potential difference, V between the ends of the specimen. For the specific heat measurements, a homogeneous constant Joule heating was imposed on the sample. The initial rise of 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 she heat capacity per unit volume, regardless of heat losses.

The specimens used in this work were pure Ni and 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 Ni–Cr 0.12 at.% sample: 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 for each sample $K(T)$ falls sharply with increasing T up to about the critical temperature, T_c, where a fairly sharp minimum is observed. This is in contrast to the picture found for Ni–Mn

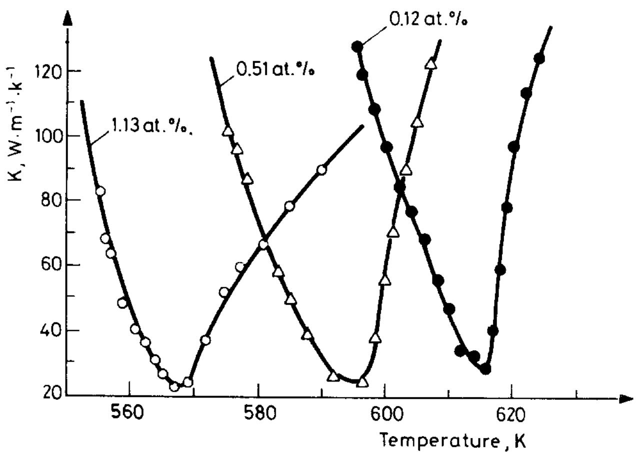

Fig. 1 Thermal conductivity K *vs.* temperature for three Ni–Cr alloys. ○ 1.13 at.%, △ 0.51 at.%, × 0.12 at.%

alloys, where only a flat minimum was observed [3]. The reasons for this minimum in $K(T)$ and the critical behaviour of the magnetic thermal resistivity have been analytically discussed for the case of pure Ni in a separate paper [7]. It can also be seen from Fig. 1 that the critical temperature T_c decreases linearly with increasing Cr concentration, accompanied by a rounding of the minimum in $K(T)$. This is in quite good qualitative agreement with the electrical resistivity results [4] and in quantitative agreement with the specific heat data [5] on the same samples.

The electrical resistivity data, as calculated directly from the *I vs. V* characteristic

Table 1 Electrical resistivity as calculated from *I vs. V* curves for Ni–Cr 0,12 at.% sample, compared with previously reported values

T, K	ϱ, $\Omega \cdot m \cdot 10^8$ present	ϱ, $\Omega \cdot m \cdot 10^8$ previous [4]
600	24.04	23.88
	24.14	24.02
602	24.22	24.16
606	24.33	24.32
608	24.41	24.44
610	24.54	24.62
612	24.67	24.77
614	24.77	24.91
616	24.89	25.10
618	25.06	25.27
620	25.20	25.42
622	25.27	25.49
624	25.35	25.56
626	25.41	25.63
628	25.57	25.72
630	25.64	25.81

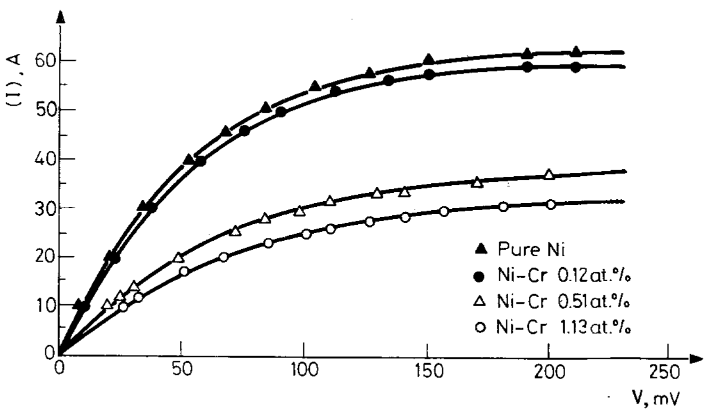

Fig. 2 Current-Voltage curve for pure Ni and three Ni–Cr alloys. ■ Pure Ni, × Ni–Cr 0.12 at.%, △ Ni–Cr 0,51 at.%, ○ Ni–Cr 1.13 at.%

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 shows 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 depicts the initial rise of temperature against time for pure Ni and the

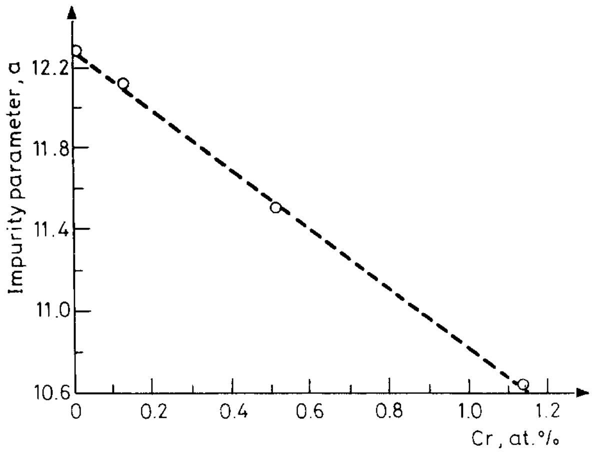

Fig. 3 Impurity parameter *vs.* Cr concentration

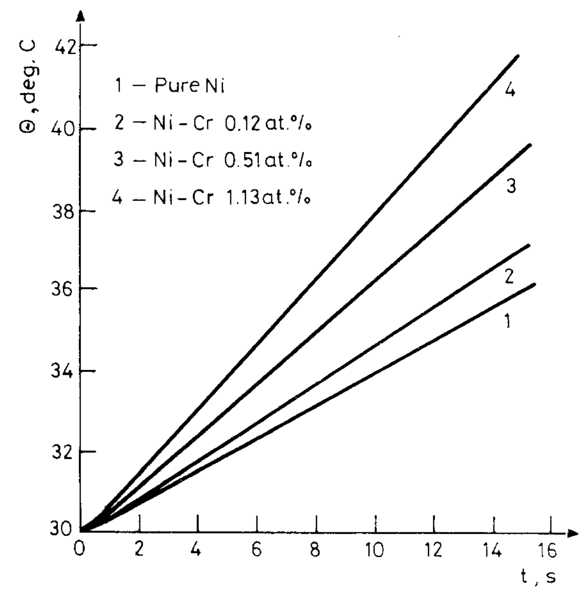

Fig. 4 Recorded temperature rise due to joule heating of the wire *vs.* time at 27 °C, 1 Pure Ni, 2 Ni–Cr 0.12 at.%, 3 Ni–Cr 0.51 at.%, 4 Ni–Cr 1.13 at.%

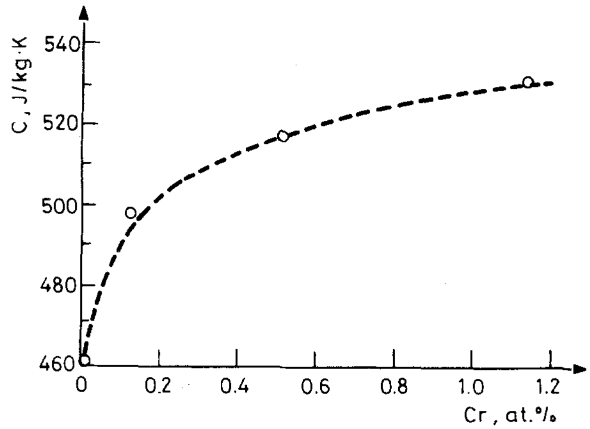

Fig. 5 Specific heat C *vs.* Cr concentration together with that of pure Ni

three diluted samples, from which the specific heat data were calculated. Figure 5 gives the specific heat C_p as a function of 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.

References

1 P. J. Jackson and N. H. Saunders, Physics Letters, 28 A (1968) 19.
2 A. S. A. Ammar, Ali M. Okaz and Naim D. Tooma, Phase transitions, 1 (1980) 325.
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.
5 A. S. A. Ammar, Ali M. Okaz and M. El-Osairy, Accepted for Publication in Ind. J. Physics, to be appeared in April issue (1988).
6 Ali M. Okaz, M. El-Osairy and N. S. Mahmoud, The Bulletin Fac. Eng. Alex. Univ., Vol. XXV (1986) 101.
7 Ali M. Okaz, M. El-Osairy and N. S. Mahmoud, The Bulletin Fac. Eng. Alex. Univ., Vol. XXVI (1987) 503.

Zusammenfassung — Die ferromagnetische Phasenumwandlung von Cr–Ni Legierungen wurde über die Temperaturabhängigkeit der Wärmeleitfähigkeit dieser Proben in der Nähe der Phasenumwandlung untersucht. Mit einem einzigen Instrument [1] konnten für die drei Stäbchenproben mit einem Cr-Gehalt von 0,12, 0,51 und 1,13% die elektrische als auch die Wärmeleitfähigkeit bestimmt werden. Zur Bestimmung des Verhältnisses von Wärme- und elektrischer Leitfähigkeit wurde eine Spannungs-Temperatur-Beziehung [2] angewendet. Unter Hinzunahme des aus den charakteristischen Stromstärke-Spannungsdiagrammen (I–U) ermittelten specizifischen elektrischen Widerstandes konnten dann die Leitfähigkeitangaben ermittelt werden. Es wurde ein Modell zur Interpretation des Effektes der Cr-Konzentration auf die I–U Diagramme entwickelt und getestet. Außerdem wurde der Effekt der Cr-Konzentration auf die specifische Wärme dargestellt.

Резюме — Ферромагнитный фазовый переход, наблюдаемый в разбавленных сплавах Cr–Ni, был изучен путем количественных измерений температурной зависимости термической проводимости этих сплавов вблизи температуры перехода. Один и тот же прибор был использован для измерений термической и электрической проводимости, а также удельной теплоемкости трех тонких стержневидных образцов сплава с концентрацией хрома равной 0,12; 0,51 и 1,13 атомных процента. Вольт-температурная зависимость была использована для измерения отношения между термической и электрической проводимостями. данные по термической проводимости были затем определены, используя данные электрического удельного сопротивления, полученных из измеренных вольт-амперных характеристик. Предложена и испытана модель, описывающая влияние концентрации хрома на вольт-амперные зависимости. Показано влияние концентрации хрома на удельную теплоемкость.