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Abstract. – Bulk and shear moduli of Cr-Ru alloys in the concentration range $11 \leq c \leq 20$ at.% Ru are reported. Phase changes previously observed at 170 K in the magnetic susceptibility of these alloys were not observed in the temperature behaviour of the elastic moduli.

Cr can dissolve up to 25 at.% Ru and still retain its bcc structure [1]. The addition of Ru has interesting effects on the magnetic and electrical properties of Cr. Nishihara *et al.* [2] observed superconductivity for concentrations (c) larger than 17 at.% Ru as well as peaks in the magnetic susceptibility at a temperature of 170 K, nearly independent of concentration in the range $14 \leq c \leq 25$ at.% Ru, and suggested that superconductivity and antiferromagnetism coexist in these alloys. This suggestion is based on the assumption that the peaks in the susceptibility curves are associated with an antiferromagnetic transition. It may, however, in the words of Nishihara *et al.* [2], also be associated with some other (unknown) phase transition. As magnetic effects are usually clearly observed [3] in the temperature dependence of the elastic constants of Cr and its alloys, we searched for the phase transitions at 170 K in the temperature dependence of the elasticity of a series of Cr-Ru alloys.

Six alloys containing 11, 14, 15, 16, 18 and 20 at.% Ru were prepared by arc melting from 99.99 % -pure Cr and 99.9 % -pure Ru. Our alloys had the same purities and we used the same preparation method as Nishihara *et al.* [2]. Bulk moduli (B) and shear moduli (G) were measured from 77 K to 500 K using ultrasonic methods described elsewhere [3]. B and G were measured for samples in both the as-cast and annealed states (1 000 °C for three days). X-ray diffraction revealed only bcc lines without any extra phases.

The phase transitions observed at 170 K by Nishihara *et al.* [2] in the magnetic susceptibility were not observed in the elastic behaviour. Instead, well defined anomalies in the B-T curves, very similar to those usually observed [3] for other Cr alloys that show a second order phase change at the Néel temperature (T_N), were observed near temperatures different from 170 K, i.e. near 430 K, 295 K, 240 K and 145 K for c = 11, 14, 15 and 16 at.% Ru respectively. Typical examples of the annealed and as-cast states are shown in figure 1. The anomalies in the B-T curves were taken to occur at T_N. T_N, defined [3] as the temperature above the minimum where the B-T curves show an inflection point, was determined to be (430 ± 10) K, (295 ± 10) K, (240 ± 10) K and (145 ± 10) K for c = 11, 14, 15 and 16 at.% Ru respectively. The transition at T_N is sharper in the annealed than in the as-cast samples.

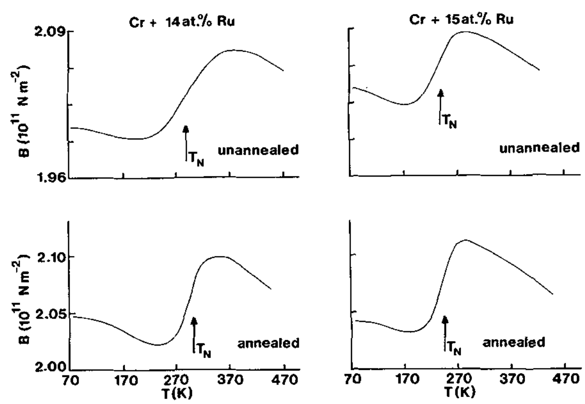

Fig. 1. – Temperature dependence of the bulk modulus of Cr-Ru alloys. The experimental error in the absolute value of B is about 1 % while changes of the order of 5 in 10^4 with temperature could be detected easily.

No anomalies were observed in the B-T curves of the two alloys containing 18 and 20 at.% Ru, suggesting that the transition to the antiferromagnetic state, if it exists, lies below 77 K and not at 170 K as suggested by Nishihara *et al.* [2]. A typical example for c = 20 at.% Ru is shown by the broken line of figure 2. On the other hand, G was found to vary smoothly through T_N as well as through 170 K for all the samples without any trace of a phase transition.

Unusually low ultrasonic attenuation was observed in the alloys. This is probably connected with the fact that, while most other dilute Cr-alloys are usually very brittle, the Cr-Ru alloys studied are not brittle at all.

The magnetic contribution to B,

$$\Delta B = B_{\mathrm{nm}} - B_{\mathrm{af}},$$

where B_{nm} represents the bulk modulus of the alloy if it were non-magnetic at $T < T_N$ and B_{af} that of the antiferromagnetic alloy, in the 11, 14, 15 and

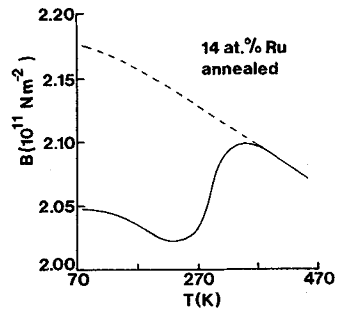

Fig. 2. – Temperature dependence of the bulk modulus of a 14 at.% Ru alloy (solid line) and a 20 at.% Ru alloy (broken line).

16 at.% Ru alloys were determined in the following way. The temperature dependence of B of the alloy containing 20 at.% Ru that shows no magnetic transitions down to 77 K, was taken to represent the non-magnetic behaviour of the antiferromagnetic Cr-Ru alloys at $T > 77$ K. The B (Cr + 20 at.% Ru)-curve was then superposed on the B-curve of each alloy at high temperatures as shown in figure 2. Subtraction of the values of the two curves gives ΔB. An example is shown in figure 3.

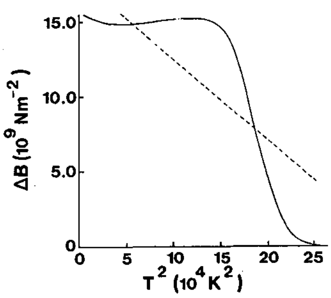

Fig. 3. – The magnetic contribution to the bulk modulus plotted against T^2 (solid line). The broken line shows the expected dependence.

According to existing itinerant electron theories [4, 5]

$$\Delta B = -4\phi_{\mathrm{m}} \left(\partial \ln T_{\mathrm{N}}/\partial\omega\right)^2 \left(3 - T^2/T_{\mathrm{N}}^2\right) \qquad (1)$$

for dilute Cr alloys. Here ϕ_{m} is an exitation potential and ω a relative volume change. According to equation (1) ΔB depends on T^2. This relation does not hold for the 11, 14, 15 and 16 % Ru samples which show magnetic transitions at $T < 77$ K. A typical example is shown in figure 3. ΔB for each alloy becomes almost temperature independent at low temperatures (Fig. 3).

In conclusion, the phase changes observed at 170 K in the magnetic susceptibility of Cr-Ru alloys by Nishihara *et al.* [2], were not observed in the elastic moduli of the alloys. A reinterpretation of the peaks in the magnetic susceptibility may be necessary. We note in this regard that a maximum in the magnetic susceptibility of for instance the Cr-Ge system, is not always indicative of the existence of antiferromagnetic ordering [6].

Acknowledgments

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[1] Waterstrat, R. M., *J. Less-Common Met.* **80** (1981) P31.

[2] Nishihara, Y., Yamaguchi, Y., Tokumoto, M., Takeda, K. and Fukamichi, K., *Phys. Rev. B* **34** (1986) 3446.

[3] Alberts, H. L. and Lourens, J. A. J., *Phys. Rev. B* **29** (1984) 5279.

[4] Steinemann, S. G., *J. Magn. Magn. Mater.* **7** (1978) 84.

[5] Alberts, H. L. and Lourens, J. A. J., *J. Phys. F.* **13** (1983) 873.

[6] Kolenda, M., Leciejewicz, J. and Szytula, A., *Phys. Status Solidi B* **57** (1973) K107.