ELSEVIER

Journal of Alloys and Compounds 235 (1996) 77–79

Journal of ALLOYS AND COMPOUNDS

Magnetic properties of $Tb_{1-x}U_xCo_5$ single crystals

A.V. Andreev[1]

Low Temperature Section, Institute of Physics, Academy of Sciences, Na Slovance 2, 180 40 Prague 8, Czech Republic

Received 16 October 1995

Abstract

U forms solid solutions in $TbCo_5$ up to $x = 0.6$ with contraction of lattice in the basal plane and expansion along the c axis. The Curie temperature and the Co magnetic moment decrease with increasing U content. The interval of spin reorientation shifts to lower temperatures.

Keywords: Uranium intermetallics; Rare earth intermetallics; Magnetic anisotropy; Spin reorientation

1. Introduction

Magnetic properties of $UCo_{5.3}$, the Co-richest compound in the U–Co phase diagram, were the point of interest of several studies [1–5]. This is a highly anisotropic uniaxial ferromagnet with relatively low molecular magnetic moment ($\mu_m = 2.4\ \mu_B$ at 4.2 K) and Curie temperature ($T_C = 365$ K). From the magnetic point of view, $UCo_{5.3}$ belongs to the series of RCo_5 compounds with a nonmagnetic R component (R here is a rare-earth metal, Y and Th). The U atoms do not carry a magnetic moment and transfer a larger number of electrons (compared with Y, Ce and Th) into the Co 3d band, which is the reason of low μ_m and T_c. However, $UCo_{5.3}$ is not isostructural with RCo_5. Studies of several U solid solutions in RCo_5 showed wide but limited solubility of U in phases with the $CaCu_5$-type structure. These studies dealt with Y (nonmagnetic R) and light rare-earth Nd and Sm (ferromagnetic R–Co coupling) [6,7]. Now, the results obtained on single crystals of similar systems with representative of heavy R, $Tb_{1-x}U_xCo_5$ (ferrimagnetic coupling between the R and Co sublattices) are presented. The parent compound $TbCo_{5+x}$ (single-phase state corresponds to $x = 0.1$–0.2) is a ferrimagnet with low molecular magnetic moment at 4.2 K (single-crystal data 0.55 μ_B for $x = 0.1$ [8] and 0.25 μ_B for $x = 0.2$ [9]), high $T_C = 980$ K and basal-plane type of magnetic anisotropy. Two spin-reorientation second-order phase transitions in which the easy-magnetization direction changes from the basal plane to the c axis via an easy cone occur in the narrow temperature range around 400 K [10].

2. Experimental details

The $Tb_{1-x}U_xCo_5$ alloys were prepared by melting the components (Tb and U purity 99.8%; Co 99.99%) in an induction furnace under a protective helium atmosphere. Samples for the measurements were cut from large (about 3 mm) grains and polished perpendicular to the a and c axes. Magnetization was measured with a vibrating sample magnetometer in fields up to 2 T in the 4.2–1000 K temperature interval.

3. Results and discussion

As in the other $R_{1-x}U_xCo_5$ systems studied, the homogeneity range of the phase with hexagonal $CaCu_5$-type structure is found to be up to $x = 0.6$. The alloys with $0.6 < x < 1.0$ consist of two phases, $Tb_{0.4}U_{0.6}Co_5$ and $UCo_{5.3}$. Within the homogeneity range, the lattice expands linearly along the c axis and contracts in the basal plane with increasing U content (Fig. 1). This leads to a fast increase of the c/a ratio. The limit of solubility corresponds well to $c/a \approx 0.84$

[1] Present address: Department of Metal Physics, Charles University, Ke Karlovu 5, 12116 Prague 2, Czech Republic. E-mail: andreev@met.mff.cuni.cz.

SSDI 0925-8388(95)02155-8

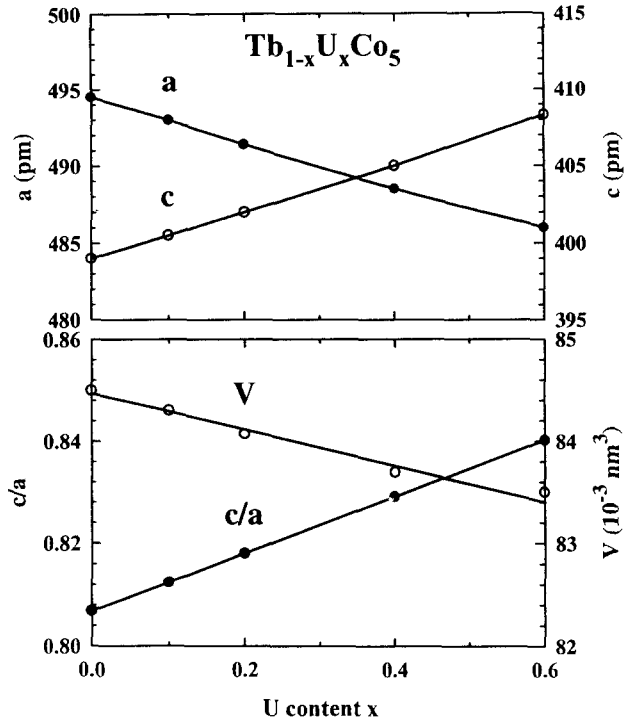

Fig. 1. Concentration dependences of lattice parameters, c/a ratio and unit-cell volume.

which is considered as the critical value for stability of the $CaCu_5$ structure [11]. This stability is known to decrease in the RCo_5 series with decreasing R atomic radius [12]. Since the atomic radius of U is smaller than that of the rare earths (which reflects a decrease in unit cell volume, Fig. 1), the isostructural U–Co binary compound does not form in the related $CaCu_5$ structure, but in its own rhombohedral lattice [1,4].

Fig. 2 shows temperature dependences of spontaneous magnetization of compounds from the homogeneity range, found from temperature scans in a 0.5 T field applied along the easy-magnetization direction of single crystals. All the compounds exhibit ferrimagnetic behaviour. Whereas $TbCo_5$ has a compensation point at 110 K, the magnetic moment of the Tb sublattice in other samples studied is smaller than that of the Co sublattice in the whole temperature range of magnetic ordering, and the compensation point on $M(T)$ dependence disappears for $x > 0.1$. From these data, the values of μ_m and T_C presented in Fig. 3 were determined. $T_C(x)$ behaviour is very similar to that in other $R_{1-x}U_xCo_5$ studied. Concentration compensation of the magnetic moment occurs at $x = 0.1$. Assuming a nonmagnetic state of U and $\mu_{Tb} = 9\ \mu_B$, the magnetic moment per Co atom is found to decrease with increasing U content in a similar way to the Y analogues, only slightly slower (Fig. 4). In both cases, the extrapolation to $x = 1$ gives much a larger μ_{Co} value than actually observed in $UCo_{5.3}$.

All the compounds within the homogeneity range

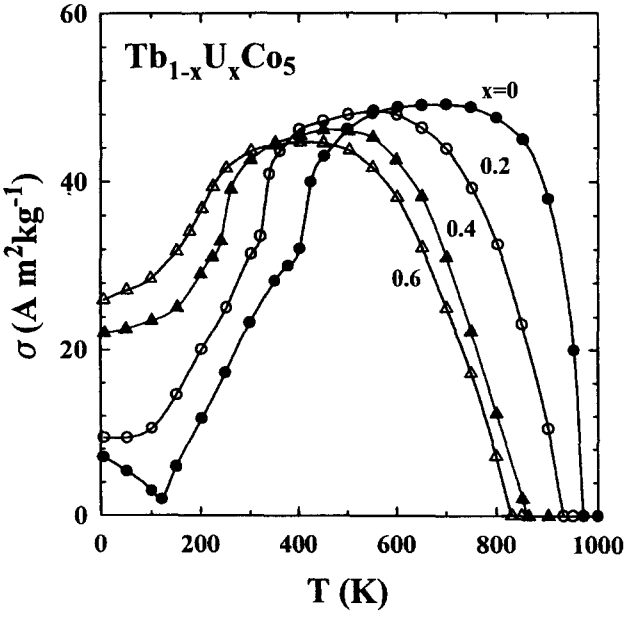

Fig. 2. Temperature dependences of spontaneous magnetization.

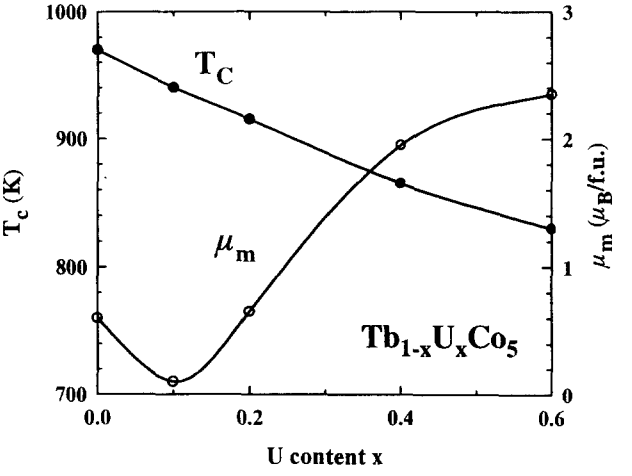

Fig. 3. Concentration dependences of Curie temperature and molecular magnetic moment.

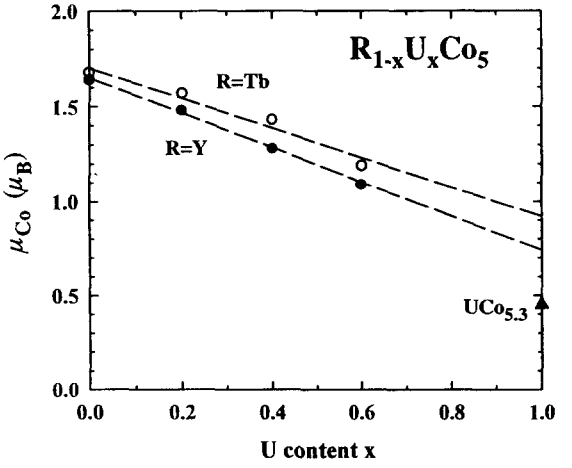

Fig. 4. Concentration dependences of the Co magnetic moment.

have basal-plane magnetic anisotropy at low temperatures and undergo spin reorientation to the uniaxial anisotropy with increasing temperature, passing through a narrow range of cone of easy axes. This is illustrated in Fig. 5, which shows the temperature dependence of magnetization along the a and c axes of the $Tb_{0.6}U_{0.4}Co_5$ crystal in a 0.5 T field. Measurements along the easy-magnetization direction at each temperature reveal in this compound (as well as in $Tb_{0.8}U_{0.2}Co_5$, Fig. 2) an anomalous additional rise of magnetization during spin reorientation, which has been found previously in $TbCo_5$ and is connected with the anisotropy of the magnitude of the Tb and Co magnetic moments [13]. Since the U atoms are considered to be nonmagnetic in $R_{1-x}U_xCo_5$ [6,7], the U substitution should reduce the basal-plane contribution to the anisotropy due to the dilution of the Tb sublattice. However, U also strongly reduces the uniaxial magnetic anisotropy of the Co sublattice [6]. Fig. 6 shows the temperature dependences of the angle Θ between the easy magnetization axis and the c axis. Since the range of spin reorientation moves to lower temperatures with increasing U content, U influences the Tb sublattice more strongly than the Co sublattice.

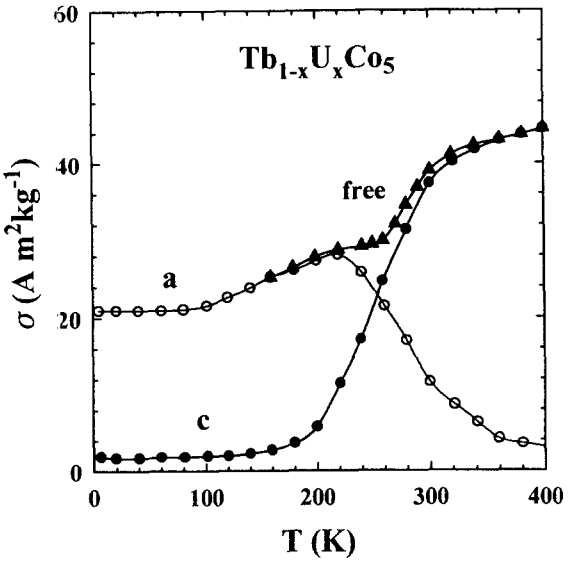

Fig. 5. Temperature dependences of magnetization in a 0.5 T field along the a and c axes and along the easy-magnetization direction of the $Tb_{0.6}U_{0.4}Co_5$ crystal.

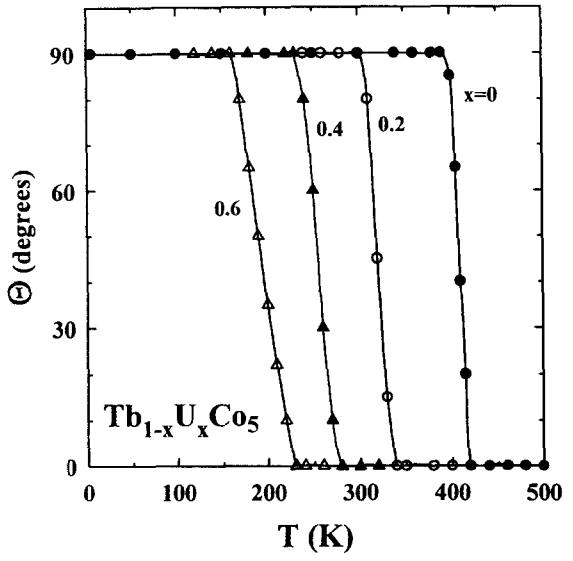

Fig. 6. Temperature dependences of angle between the c axis and the easy-magnetization direction.

References

[1] A.V. Deryagin and A.V. Andreev, *Sov. Phys. JETP, 44* (1976) 610.
[2] A.S. Yermolenko, A.V. Ivanov, V.Ye. Komarov, L.M. Magat, G.M. Makarova and Ya.S. Shur, *Phys. Met. Metallogr. (USSR), 43* (2) (1977) 195.
[3] F.U. Hillebrecht, D.D. Sarma and N. Martensson, *J. Magn. Magn. Mater., 52* (1985) 129.
[4] A. Dommann, H. Brändle, F. Hulliger and P. Fischer, *J. Less-Common Met., 158* (1990) 287.
[5] H. Brändle, J. Schoenes and F. Hulliger, *J. Magn. Magn. Mater., 83* (1990) 29.
[6] A.V. Deryagin, A.V. Andreev and V.A. Reimer, *Sov. Phys. JETP, 47* (1978) 933.
[7] A.V. Andreev, *Digest of 22 Journees des Actinides*, Meribel, 1992, p. 159.
[8] A.S. Yermolenko, Magnetism of highly anisotropic rare-earth compounds RCo_5, *Dissertation of Doctor of Sciences*, Sverdlovsk, 1983 (in Russian).
[9] R. Ballou, B. Gorges, R. Lemaire, H. Rakoto and J.C. Ousset, *Physica B, 155* (1989) 266.
[10] J. Okamoto, H. Fujii, C. Inoue and E. Tatsumoto, *J. Phys. Soc. Jpn., 34* (1973) 835.
[11] A.V. Andreev, *Physica B, 172* (1991) 377.
[12] K.H.J. Buschow, *J. Less-Common Met., 29* (1972) 283.
[13] A.N. Pirogov, V.V. Kelarev, A.S. Ermolenko, V.V. Chuev, S.K. Sidorov and A.M. Artamonova, *Sov. Phys. JETP, 56* (1978) 804.