UvA-DARE (Digital Academic Repository)

Fe substitution effects on the magnetic properties of the $\text{RCo}_4\text{-xFexAl}$ compounds (R Ho and Y)

Thang, C.V.; Tai, L.T.; Thuy, N.P.; Hien, T.D.; Franse, J.J.M.

DOI

[10.1016/0304-8853\(94\)00760-8](https://doi.org/10.1016/0304-8853(94)00760-8)

Publication date

1995

Published in

Journal of Magnetism and Magnetic Materials

[Link to publication](#)

Citation for published version (APA):

Thang, C. V., Tai, L. T., Thuy, N. P., Hien, T. D., & Franse, J. J. M. (1995). Fe substitution effects on the magnetic properties of the $\text{RCo}_4\text{-xFexAl}$ compounds (R Ho and Y). *Journal of Magnetism and Magnetic Materials*, 140-144, 935-936. [https://doi.org/10.1016/0304-8853\(94\)00760-8](https://doi.org/10.1016/0304-8853(94)00760-8)

General rights

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: <https://uba.uva.nl/en/contact>, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

ELSEVIER

Fe substitution effects on the magnetic properties of the $\text{RCo}_{4-x}\text{Fe}_x\text{Al}$ compounds (R: Ho and Y)

C.V. Thang^{a,b}, L.T. Tai^a, J.P. Liu^b, N.P. Thuy^a, T.D. Hien^a, J.J.M. Franse^{b,*}

^a Cryogenic laboratory, Faculty of Physics, University of Hanoi, Viet Nam

^b Van der Waals–Zeeman Laboratory, University of Amsterdam, Valckenierstraat 65, 1018 XE Amsterdam, The Netherlands

Abstract

Fe substitution for Co leads to the increase of the Curie temperatures of both $\text{HoCo}_{4-x}\text{Fe}_x\text{Al}$ and $\text{YCo}_{4-x}\text{Fe}_x\text{Al}$ and of the spin-reorientation temperature of $\text{HoCo}_{4-x}\text{Fe}_x\text{Al}$. In contrary, the anisotropy field of $\text{YCo}_{4-x}\text{Fe}_x\text{Al}$ decreases quickly with increasing Fe content. The results are explained in terms of the individual site anisotropy model.

$\text{RCo}_{5-x}\text{Al}_x$ ($x \leq 2$) compounds with CaCu_5 structure have recently been studied. RCo_4Al has been stressed in order to compare the magnetic properties with those of RCo_4B [1,2]. Al substitution for Co strongly diminishes the Curie temperature, the Co atomic moment and the magnetocrystalline anisotropy (MCA) of both R and 3d sublattices. To further study the magnetic properties of the 3d sublattice of RCo_4Al , in this paper the effects of Fe substitution on the magnetic properties of $\text{RCo}_{4-x}\text{Fe}_x\text{Al}$ (R = Y and Ho) have been studied.

The ingots of $\text{RCo}_{4-x}\text{Fe}_x\text{Al}$ ($x = 0.0\text{--}4.0$) were prepared by arc melting the constituent elements of high purity (at least 99.9%) and then annealed at 900°C for about 50–70 h. The magnetically aligned samples were prepared by solidifying the mixture of sample powders and epoxy resin in a magnetic field of 1.1 T at room temperature. X-ray diffraction and magnetic measurements were carried out on the bulk, powdered and aligned samples. It turns out that the samples with $x \leq 1.8$ for $\text{YCo}_{4-x}\text{Fe}_x\text{Al}$ and $x \leq 1.5$ for $\text{HoCo}_{4-x}\text{Fe}_x\text{Al}$ are generally single phase with the CaCu_5 structure. The $\text{YCo}_2\text{Fe}_2\text{Al}$ and $\text{YCo}_{1.8}\text{Fe}_{2.2}\text{Al}$ samples contain a small amount of a second phase, while the samples with higher Fe content are found to be multiphase and are not considered in the following part of this paper. Pulsed magnetic fields up to 3.5 T have been used to measure the aligned samples at 77 and 300 K. Values for the anisotropy field H_a of the samples with uniaxial anisotropy were approximately estimated by extrapolating the magnetization curves measured along the easy and hard magnetization directions to their intersection.

The composition dependences of the obtained magnetic parameters of $\text{HoCo}_{4-x}\text{Fe}_x\text{Al}$ and of the Curie temperature of $\text{YCo}_{4-x}\text{Fe}_x\text{Al}$ are shown in Fig. 1 and in the inset of Fig. 1, respectively. It can be seen that with increasing Fe content, the Curie temperature T_C increases for both systems and tends to reach a constant value at about $x \approx 1.4$. This effect of Fe substitution on the Curie temperature of RCo_4Al is in good accordance with those obtained for the Co–rare-earth intermetallics RCo_5 and RCo_4B [4]. In contrast, the ratio T_k/T_C (T_k is the compensation temperature) decreases when the Fe content increases. This result can be explained by taking into account the larger magnetic moment of Fe compared to that of Co, which leads to an increase of the 3d-sublattice moment [4].

In a low magnetic field (0.1 T), an anomalous temperature dependence of the magnetization can be observed for the $\text{HoCo}_{4-x}\text{Fe}_x\text{Al}$ samples with $x < 1.5$, which is considered to be associated with the spin-reorientation transition as also confirmed by ac susceptibility measurements and by the temperature dependence of the magnetization of aligned samples (not shown here). In addition, an enhancement of the 002 and 001 peaks can be observed from the diffraction patterns of the aligned samples, which confirms the uniaxial anisotropy along the *c*-axis of the samples with $x < 1$ at room temperature. Thus, the observed spin-reorientation transition is from planar to uniaxial anisotropy with increasing temperature. It is found that the spin-reorientation temperature increases with increasing Fe content (see Fig. 1).

In Fig. 2, the composition dependence of H_a for $\text{YCo}_{4-x}\text{Fe}_x\text{Al}$ at 77 and 300 K is presented. The data for YCo_4Al were quoted from Ref. [2]. It can be seen that with increasing Fe content, H_a decreases quickly and tends to change its sign at about $x = 2.0$. In combination with X-ray diffraction patterns of the aligned samples (not

* Corresponding author. Fax: +31-20-525 5788.

Fig. 1. Composition dependences of the Curie temperature T_C , the compensation temperature T_K , the spin-reorientation temperature T_{sr} of $\text{HoCo}_{4-x}\text{Fe}_x\text{Al}$ and of the Curie temperature T_C of $\text{YCo}_{4-x}\text{Fe}_x\text{Al}$ (inset). The lines are guides to the eyes.

shown here) it can be suggested that in the temperature range of 77–300 K, the samples with $x < 2.0$ show an uniaxial anisotropy whereas the sample with $x = 2.2$ has a planar one. A conical anisotropy at room temperature is also suggested for the sample with $x = 2.0$. It is evident that Fe substitution leads to a strong decrease in the positive MCA of YCo_4Al . Also, if we consider the observed spin-reorientation transition in HoCo_4Al as a result of the competition between the positive MCA of Co sublattice and the negative one of Ho sublattice, the observed increase of the spin-reorientation temperature with increasing Fe content can be regarded to result from the decrease of the positive MCA of the 3d sublattice. This effect of Fe substitution can be explained on the basis of the individual site anisotropy (ISA) model [4,10], in which the overall MCA of 3d sublattice is considered to be the sum of the independent contributions coming from the

Fig. 2. Composition dependence of the anisotropy field H_a of $\text{YCo}_{4-x}\text{Fe}_x\text{Al}$ at 77 and 300 K. The data for YCo_4Al were quoted from Ref. [2]. The lines are used for guiding the eyes.

individual 3d sites. In rare-earth–transition-metal intermetallics with CaCu_5 structure, there are two crystallographic sites for the transition metal, namely 2c and 3g. As evidenced from nuclear magnetic resonance (NMR) measurements on RCO_5 , the Co ions at the 2c site give a large positive contribution to the overall anisotropy whereas the Co ions at the 3g site give a small negative one [5,6]. In addition, in substituted $\text{R}_n\text{Co}_{m-x}\text{Fe}_x$ compounds the preferential occupation at some crystallographic sites of Fe ions has been observed by means of neutron diffraction and Mössbauer effect studies [7–9]. Fe and Co ions usually give contributions of opposite signs at the same crystallographic site [4,10]. The decrease of the positive MCA of the 3d sublattice with increasing Fe content obtained above, therefore, suggests that Fe ions preferably occupy the 2c site. At this site, Fe ions have a negative MCA, which competes with the positive one of the Co ions. It should be noticed that Fe ions in $\text{RCo}_{4-x}\text{Fe}_x\text{B}$ (CeCo_4B structure) also prefer the 2c site [7,8] whereas for $\text{RCO}_{5-x}\text{Fe}_x$, in contrast, Fe ions prefer the 3g site [9]. Recently Konno et al. [3] have reported that the distribution of Al in $\text{RCO}_{5-x}\text{Al}_x$ is not necessarily random. The Al atoms, furthermore, can prefer the 3g site to the 2c site [3]. Thus the Al substitution for Co in RCO_4Al is suggested to strongly modify the environment of the crystallographic sites of RCO_5 compounds, which leads to a large influence on the occupation of Fe ions in $\text{RCo}_{4-x}\text{Fe}_x\text{Al}$.

References

- [1] K. Konno, H. Ido and K. Maki, *J. Magn. Magn. Mater.* 104–107 (1992) 1369.
- [2] H. Ido, K. Konno, S.F. Cheng, S.G. Sankar and W.E. Wallace, *Proc. 11th Int. Workshop RE-Magnets and 6th Inter. Symp. on Magn. Anis. Coerc. RE-TM Alloys*, Pittsburgh, Pennsylvania, USA 1990, Part II, ed. S.G. Sankar, p. 80.
- [3] K. Konno, H. Ido, S.F. Cheng, S.G. Sankar and W.E. Wallace, *J. Appl. Phys.* 73 (1993) 5929.
- [4] N.P. Thuy, N.M. Hong, T.D. Hien and J.J.M. Franse, *Proc. 11th Int. Workshop RE-Magnets and 6th Inter. Symp. on Magn. Anis. Coerc. RE-TM Alloys*, Pittsburgh, Pennsylvania, USA, 1990, Part II, ed. S.G. Sankar, p. 60.
- [5] R.L. Streever, *Phys. Rev. B* 79 (1979) 2704.
- [6] H. Yoshie, K. Ogino, H. Nagai, A. Tsujimura and Y. Nakamura, *J. Magn. Magn. Mater.* 70 (1987) 303.
- [7] Y. Gros, F. Hartmann-Boutron, C. Meyer, M.A. Fremy, P. Ternaude and P. Auric, *J. de Phys.* 49 (1988) C8-547.
- [8] H. Onodera, S.G. Kang, H. Yamauchi and Y. Yamauchi, *J. Magn. Magn. Mater.* 127 (1993) 298.
- [9] J. Laforest and J.S. Shah, *IEEE Trans. Magn.* 9 (1973) 217.
- [10] J.J.M. Franse, F.E. Kayzel and N.P. Thuy, *J. Magn. Magn. Mater.* 129 (1994) 26.