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Spontaneous magnetostriction of $Y_2Fe_{16}Al$ compound*

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The structure and magnetic properties of $Y_2Fe_{16}Al$ compound have been investigated by means of x-ray diffraction and magnetization measurements. The $Y_2Fe_{16}Al$ compound has a hexagonal Th_2Ni_{17}-type structure. Negative thermal expansion was found in $Y_2Fe_{16}Al$ compound in the temperature range from 332 to 438K by x-ray dilatometry. The coefficient of the average thermal expansion is $\overline{\alpha} = -3.4 \times 10^{-5}K^{-1}$. The spontaneous magnetostrictive deformations from 293 to 427K have been calculated based on the differences between the experimental values of the lattice parameters and the corresponding values extrapolated from the paramagnetic range. The result shows that the spontaneous volume magnetostrictive deformation ω_S decreases from 5.4×10^{-3} to near zero with temperature increasing from 293 to 427K, the spontaneous linear magnetostrictive deformation λ_c along the c axis is much larger than the spontaneous linear magnetostrictive deformation λ_a in basal-plane in the same temperature range except near 427K.

Keywords: $Y_2Fe_{16}Al$ compound, negative thermal expansion, spontaneous magnetostriction
PACC: 7550B, 7530C

1. Introduction

The rare-earth iron-rich R_2Fe_{17} compounds are not suitable for permanent magnets because of their low Curie temperature and room-temperature plane magnetic anisotropy. However, It has been found that either substituting other elements into the 3D sublattice or introducing the interstitial atoms or both can enhance their magnetic properties considerably and make them interesting materials for permanent magnets.[1−5] In recent years, it was found that there is a negative thermal expansion coefficient in some R_2Fe_{17} compounds and some $R_2Fe_{17-x}Mn_x$ compounds with content of Mn, and that the temperature range of the negative thermal expansion for $R_2Fe_{17-x}Mn_x$ compounds can be altered by the change of x in a very wide temperature range including room temperature.[6−8] This makes again R_2 (Fe, Mn)$_{17}$ and R_2Fe_{17} compounds interesting materials both from a fundamental point of view and in applications for negative thermal-expansion materials. In this paper, the thermal expansion behaviour and spontaneous magnetostriction of the Y_2AlFe_{16} compound are investigated by means of x-ray diffraction and magnetization measurements. The reason that we substituted one Al atom for one Fe atom is that Al can increase the Curie temperature (319K) of Y_2Fe_{17} and this is convenient to the x-ray diffraction measurement above room-temperature.

2. Experimental

The compound Y_2AlFe_{16} was prepared by arc melting in an argon atmosphere of high purity. The raw materials of Y, Fe, and Al had at least 99.95% purity. The ingot was remelted at least three times to ensure its homogeneity and sealed in a silicon vacuum tube, then annealed at 1050°C for 7 days, and after that quenched in water. The ingot was ground into powder. To decrease the stress, the powder was sealed in a silicon vacuum tube, annealed at 300°C for 5h and slowly cooled to room temperature. The powder x-ray diffraction with Cu $K\alpha$ radiation was used to examine the phase structure of the sample.

The Curie temperature T_C was derived from the temperature dependence of the magnetization curve measured by a vibrating sample magnetometer in a low field of 40kA/m. The thermal expansion was measured by x-ray dilatometry on a diffractometer. For

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the determination of the lattice parameter a and c of the Y_2AlFe_{16} compound in the temperature range from 293 to 650K, the sample was placed in an evacuated high-temperature chamber and step scanning (at 0.01° intervals) x-ray diffraction patterns of the (112) and (222) reflections were recorded by the x-ray diffractometer with Cu $K\alpha$ radiation monochromatized by a single-crystal graphite monochromator. The experimental error in the determination of a and c was 10^{-4} nm. The magnetostrictive deformations ω_S, λ_a, λ_c were determined by means of the differences between the experimental values v_m, a_m, c_m of the lattice parameters at a given temperature and the corresponding values v_p, a_p, c_p extrapolated from the paramagnetic range according to Debye theory and Grüneisen relation. The value of the Debye temperature T_D, which is necessary for the extrapolation, was estimated from acoustical measurements to be 450K for Y_2Fe_{17} and 400K for the other R_2Fe_{17} compounds.[9] We used the same value 400K for the extrapolation of the temperature dependences of the lattice parameters of the sample.

3. Results and discussion

Figure 1 gives the x-ray pattern of $Y_2Fe_{16}Al$ compound at room temperature (300K). The indices of crystallographic plane (hkl) of reflections are shown in Fig.1. It indicates that $Y_2Fe_{16}Al$ compound is in a single phase with the Th_2Ni_{17}-type structure.

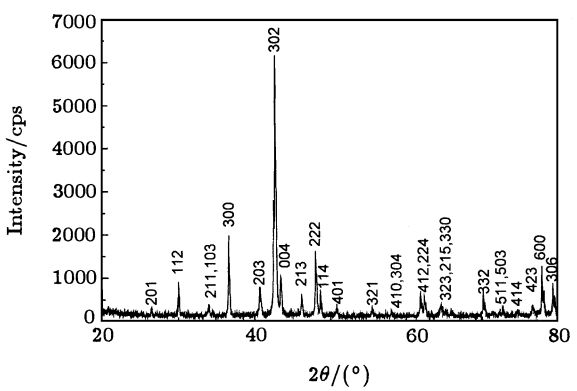


Fig.1. X-ray pattern of the $Y_2Fe_{16}Al$ compound at room temperature (300K).

Figure 2 shows the temperature dependence of the magnetization of $Y_2Fe_{16}Al$ compound in a low field 40kA/m, from which we can derive the Curie temperature of the sample, which is about 375K. The value is about 55K higher than the mother compound Y_2Fe_{17}.[10] This has been already described in other works.[10]

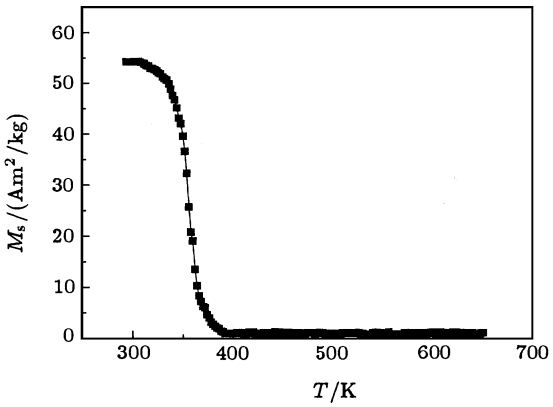


Fig.2. Temperature dependence of the magnetization of $Y_2Fe_{16}Al$ compound in a low field 40kA/m.

Figure 3 shows the temperature dependence of the unit cell volume v of $Y_2Fe_{16}Al$ compound. If the variation of the rate of v (v_m) is considered from 293 to 650K, we will have the average thermal expansion coefficients $\overline{\alpha} = \Delta v/v\Delta T = 1.3 \times 10^{-5}$/K in the temperature range 293–332K, $\overline{\alpha} = -3.4 \times 10^{-5}$/K in 332–438K, and $\overline{\alpha} = 1.5 \times 10^{-5}$/K in 438–650K, respectively. We suppose that the negative thermal expansion behaviour from 332 to 438K results not only from the decrease of the magnetic interactions but also from the sharp decreasing of the magnetic moment. This can be seen in Fig.2, which shows that the magnetic order rapidly drops from about 320K. This transition would be accompanied by a large negative volume change anomaly. Just as $Y_2Al_3Fe_{11}Mn_3$ compound in Ref.[7], we suppose its origin is intimately connected with a loss of vibrating energy which is due to an increase of the kinetic energy of the d electrons through the lattice contraction. The average thermal expansion coefficient in the temperature range 293–332K is slightly smaller than that in 438–650K, which is also correlated with the decrease of the magnetic interaction and magnetic moment with temperature increasing from 293–332K.

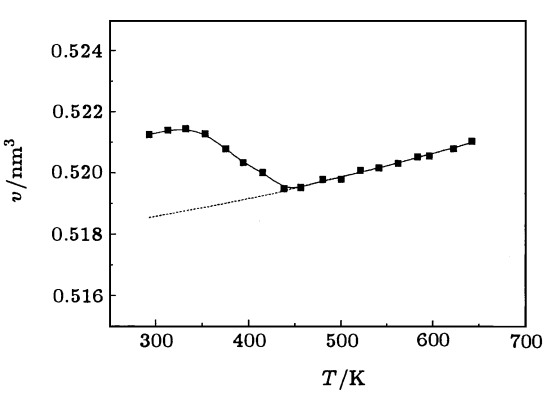


Fig.3. Temperature dependence of the unit cell volume v of $Y_2Fe_{16}Al$ compound.

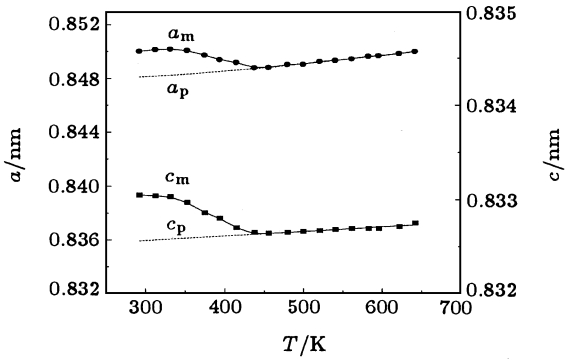


Fig.4. Temperature dependence of lattice parameters a and $c$of $Y_2Fe_{16}Al$ compound.

Figure 4 shows the temperature dependence of lattice parameters a and c. It means that the negative thermal expansion of the sample in the temperature range 332 to 438K is anisotropic.

The temperature dependences of the extrapolated values v_p, a_p, and c_p is given in Fig.3 and Fig.4, respectively. From Fig.3 and Fig.4, we can derive the temperature dependence of the spontaneous volume magnetostrictive deformation ω_S by the relation $\omega_S = (v_m - v_p)/v_p$, and the temperature dependence of the spontaneous linear magnetostrictive deformations λ_c along the c axis and λ_a in the basal-plane by the relations $\lambda_c = (c_m - c_p)/c_p$ and $\lambda_a = (a_m - a_p)/a_p$, respectively. Here the signs m and p represent the unit cell parameters in the magnetic state and paramagnetic state, respectively. The temperature dependence of ω_S is shown in Fig.5. It is obvious that the ω_S decreases from 5.4×10^{-3} to near zero with temperature increasing from 293 to 427K and the decreasing rate of the ω_S above 332K is faster than that below 332K. We suppose that the variation of ω_S above 332K maybe connected not only with the decreasing of the magnetic interaction, but also with the loss of the average magnetic moment. Otherwise the variation of ω_S below 332K maybe mainly connected with the decreasing of the magnetic interaction. The ω_S disappears at about 60K above T_C. This apparently reflects short-range ordering. The temperature dependence of λ_c and λ_a is shown in Fig.6. It is noticed that the spontaneous linear deformation λ_c is much larger than λ_a in the same temperature range except near 427K, and λ_c decreases faster than does λ_a with temperature increasing. These imply that the strength of magnetoelastic effect along the c axis is much stronger than that in the basal-plane.

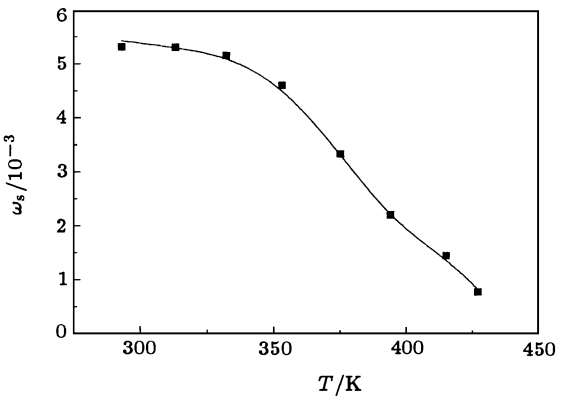


Fig.5. Temperature dependence of the spontaneous volume magnetostrictive deformation ω_S of $Y_2Fe_{16}Al$ compound.

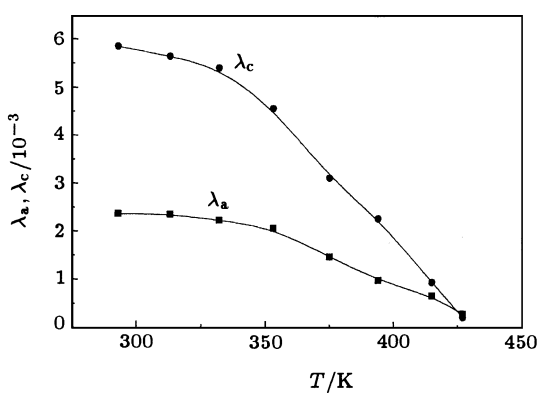


Fig.6. Temperature dependence of the spontaneous linear magnetostrictive deformations λ_c and λ_a of $Y_2Fe_{16}Al$ compound.

4. Conclusion

We can conclude that there exists an anisotropic strong spontaneous magnetostriction in Y_2AlFe_{16} compound and there is a negative thermal expansion coefficient of Y_2AlFe_{16} compound in the temperature range from 332 to 438K.

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