



MAGNETIC PROPERTIES OF $\text{YGdFe}_{17}\text{Al}$ AND $\text{YGdFe}_{16}\text{CoAl}$

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ABSTRACT

The structural and magnetic properties of the off-stoichiometric R_2Fe_{17} -type $\text{YGdFe}_{17}\text{Al}$ and $\text{YGdFe}_{16}\text{CoAl}$ compounds have been investigated by x-ray diffraction studies and magnetization and Curie temperature measurements. The saturation magnetization (M_s) increases from 82 emu/g for YGdFe_{17} to 93 emu/g for $\text{YGdFe}_{17}\text{Al}$ and 113 emu/g for $\text{YGdFe}_{16}\text{CoAl}$. The Curie temperature decreases from 476 K for YGdFe_{17} to 325 K for $\text{YGdFe}_{17}\text{Al}$ and 542 K for $\text{YGdFe}_{16}\text{CoAl}$. Both the compounds are seen to have planar anisotropy as revealed by the XRD patterns taken for magnetically aligned samples.

1. INTRODUCTION

Rare earth - iron intermetallic compounds of the type R_2Fe_{17} (R = rare earth) have attracted significant attention as possible candidates for high performance permanent magnet materials [1,2]. These compounds have been reported to crystallize in the rhombohedral $\text{Th}_2\text{Zn}_{17}$ type structure for rare earths lighter than Gd and in the hexagonal $\text{Th}_2\text{Ni}_{17}$ type structure for rare earths heavier than Tb [3]. The Curie temperatures of the R_2Fe_{17} compounds are low [Max. 387K ($\text{Sm}_2\text{Fe}_{17}$)] due to the short Fe-Fe distance at the dumbbell site leading to antiferromagnetic exchange among the iron atoms [4,5]. In addition, the room temperature anisotropy is predominantly due to the Fe sublattice and is planar [4,5]. Partial substitution of non-magnetic elements such as Al, Ga and Si for iron, or interstitial modification by N and C, has been reported to cause considerable increase in the T_C and magnetocrystalline anisotropy of these compounds [4,5]. Suresh and Rama Rao [6] have reported an increase in T_C of ErPrFe_{17} from 285 K to 435K when 3 atoms of Fe were replaced by Al. Venkatesan *et al.* [7] have reported an increase in T_C in $\text{HoErFe}_{17-x}\text{Ga}_x$ with increasing concentration of Ga up to $x=4$ and a tendency of easy magnetization direction to change towards axial from planar at $x=7$. Huang and Ching [8,9] explained the enhancement of T_C for Al, Ga, and Si substituted $\text{Nd}_2\text{Fe}_{17}$ compounds on the basis of modification of the 3d band of Fe upon substitution. Sabiryanov and Jaswal [10] have calculated the Curie temperatures of the Al/Ga/Si substituted $\text{Sm}_2\text{Fe}_{17}$ employing a model proposed by Mohn and Wohlfarth [11] that explains the dependence of T_C on the density of states (DOS) at the Fermi level. Rama Rao *et al.* [12] have reviewed the dependence of magnetic properties of R_2Fe_{17} compounds on the site occupancy of the substitutional elements. Substitution of Ga and Si for Fe in ErPrFe_{17} has been reported to cause the T_C to increase by about 250 K [13].

The magnetic properties of off-stoichiometric R_2Fe_{17} compounds of the types $\text{R}_2\text{Fe}_{14}\text{Si}_2$ and $\text{R}_2\text{Fe}_{17-x}\text{Co}_x\text{Si}$ have been investigated by Pourarian *et al* (15,16). They have reported that modification of the lattice of R_2Fe_{17} by Si and Co atoms significantly enhanced the ordering temperature T_C and caused spin reorientations with an induced uniaxial anisotropy at room temperature. Recently Ren *et al* [14] have reported that off-stoichiometric 2:17 compounds of the type $\text{Sm}_2\text{Fe}_{17-x}\text{T}_x\text{M}$ ($\text{T} = \text{Co}, \text{Ti}$) formed in rhombohedral $\text{Th}_2\text{Zn}_{17}$ structure and that the

enhancement in T_C and M_S in these compounds with x was more compared to the stoichiometric 2:17 compounds.

The variation of planar anisotropy of iron due to the substitution elements, in the absence of rare earth anisotropy can be investigated if the anisotropy at the rare earth site is zero. The present investigation deals with the effect of addition of Al and Co on the intrinsic magnetic properties of the off-stoichiometric 2:17 type YGdFe_{17} alloys.

2. EXPERIMENTAL DETAILS

Compounds with nominal compositions of $\text{YGdFe}_{17}\text{Al}$ and $\text{YGdFe}_{16}\text{CoAl}$ were prepared using an arc furnace and in argon atmosphere, starting from Y and Gd of 99.9% purity, Fe of 99.95% purity and Co of 99.99% purity. The constituents were melted several times to ensure homogeneity. The ingots were homogenized in vacuum [10^{-6} torr < pressure < 10^{-5} torr] at 950°C for seven days and furnace cooled. Structural characterization was carried out by taking x-ray diffraction patterns of sample powders employing Fe-K_α radiation. Magnetization and Curie temperature were determined using a vibrating sample magnetometer (Model No PAR 155) up to an applied field of 12 kOe. The powders were aligned in a magnetic field of 2.5 T for investigating the anisotropy and easy magnetization direction (EMD). Powders aligned perpendicular to the substrate were examined by X-ray diffraction in order to determine the EMD and those that are aligned parallel to the substrate were used to determine the anisotropy fields from magnetization measurements.

3. RESULTS AND DISCUSSION

Powder x-ray diffraction patterns for $\text{YGdFe}_{17}\text{Al}$, $\text{YGdFe}_{16}\text{CoAl}$ compounds are shown in Fig. 1. All the compounds are seen to have formed in hexagonal structure with traces of $\alpha\text{-Fe}$. The lattice parameters are tabulated in Table 1. The lattice parameters are seen to be more for the Al and Co containing compounds than for YGdFe_{17} . Also, the lattice parameters of $\text{YGdFe}_{16}\text{AlCo}$ are seen to be less than those of $\text{YGdFe}_{17}\text{Al}$. The relative sizes of the lattices are in accordance with the atomic radii of Fe, Al and Co.

The magnetization curves of the compounds are shown in Fig 2. The magnetization values in all the compounds are seen to nearly saturate. The saturation magnetization (M_S) values were found from Honda plots and are shown in Table 1. From a value of 82 emu/g for YGdFe_{17} , an increase in the value of M_S is observed with the addition of Al to 87 emu/g and a further increase to 117 emu/g with the addition of Co. This increase in M_S for $\text{YGdFe}_{17}\text{Al}$ can be attributed to the increase of Fe-Fe exchange, which might be due to the depopulation of the 3d band of the Fe atom.

In R_2Fe_{17} compounds the total magnetic moment follows the moment of Fe –sublattice for a given rare-earth sublattice. The substitution of metal or metalloid leads to a change in the density of states in the 3d band. Huang and Ching [8,9] from the band structure calculations in $\text{Nd}_2\text{Fe}_{17}$ by substituting Fe with Al, have reported that Al affects the band through 3d-(3p, 4s) hybridization. They have also obtained partial density of states (PDOS) of Al. and shown that the Al energy states are at the bottom of the 3d band thus causing a transfer of electrons from 3d to 3p the band, leading to an increase in the magnetic moment of the Fe sublattice. The increase in M_S in case of Co substituted compound can be due to the exchange between Fe and Co moments in addition to Fe-Fe exchange based on the rigid band model.

The Curie temperature (T_C) values were determined from M vs T measurements in the presence of a magnetic field of 300 Oe. The T_C decreased from 476 K for YGdFe_{17} to 325 K for $\text{YGdFe}_{17}\text{Al}$ and increased to 542 K for $\text{YGdFe}_{16}\text{CoAl}$.

According to Mohn and Wholfarth [11], the T_C for these compounds is given as

Where M_0 is the magnetization at 0 K and χ_0 is the exchange enhanced susceptibility which

$$T_C = M_0 / \chi_0$$

depends on the density of states (DOS) at the Fermi level. Al or Ga or Si, partially replacing Fe in $\text{Nd}_2\text{Fe}_{17}$, has been reported to preferentially occupy the 12j (18h) site [8,9]. Using this information, Sabiryanov and Jaswal [10] have investigated the electronic structure and T_C of $\text{Sm}_2\text{Fe}_{16}(\text{Al}/\text{Ga}/\text{Si})$ by means of self-consistent spin polarized band structure calculations on the basis of the above model and have shown a behaviour similar to the present results.

The increase in T_C of $\text{YGdFe}_{16}\text{CoAl}$ may be due to Fe- Co exchange, which is greater than Fe-Fe exchange.

The x-ray diffraction patterns for the magnetically oriented samples are shown in Fig. 3. In all the compounds only reflections corresponding to (300), (220) planes are seen indicating the presence of planar anisotropy. It has been observed that due to the addition of Al and even with Co to YGdFe_{17} there is no significant change in EMD of the parent YGdFe_{17} . The anisotropy field (H_A), values are calculated from the magnetization curves (Fig. 4) measured for the magnetically aligned samples. From the H_A values it can be seen that due to the addition of Al/Co to YGdFe_{17} , there is an increase in the anisotropic field. The reason for this increase in anisotropy is due to the decrease in planar anisotropy of Fe by the substitution of Al in case of $\text{YGdFe}_{17}\text{Al}$ and an increase in axial anisotropy by the addition of Co in $\text{YGdFe}_{16}\text{CoAl}$.

4. CONCLUSIONS

X-ray diffraction studies reveal that $\text{YGdFe}_{17}\text{Al}$ and $\text{YGdFe}_{16}\text{CoAl}$ compounds formed in hexagonal structure. The saturation magnetization (M_s) increases from 82 emu/g for YGdFe_{17} to 93 emu/g for $\text{YGdFe}_{17}\text{Al}$ and 113 emu/g for $\text{YGdFe}_{16}\text{CoAl}$. The Curie temperature decreases from 476 K for YGdFe_{17} to 325 K for $\text{YGdFe}_{17}\text{Al}$ and 542 K for $\text{YGdFe}_{16}\text{CoAl}$, which is discussed with respect to the PDOS of the substitutional elements and the exchange. Both the compounds are seen to have planar anisotropy as revealed by the XRD patterns taken for magnetically aligned samples.

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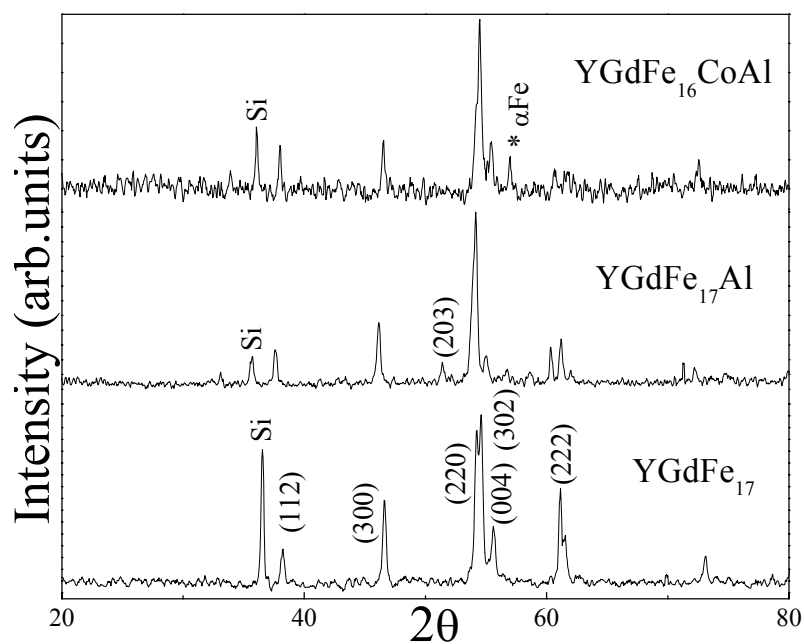
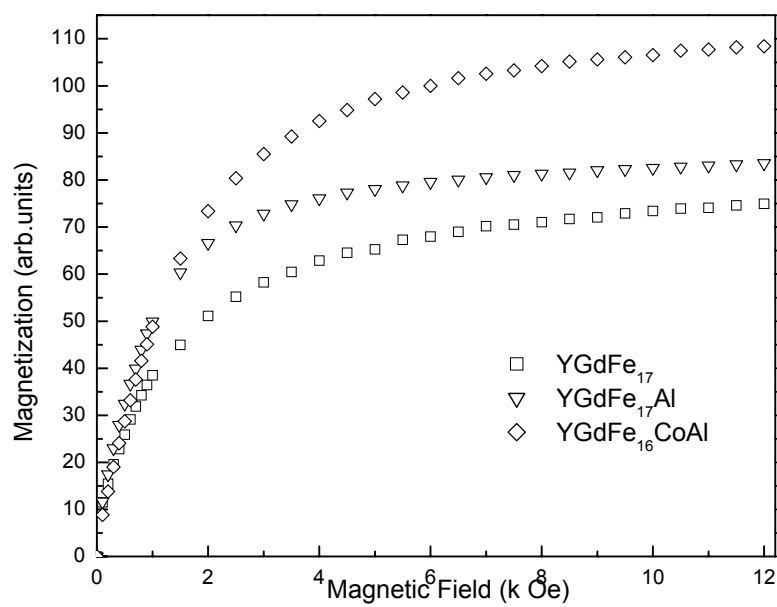
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TABLE

Table.1. Lattice parameters, unit-cell volume, Saturation magnetization, Curie-temperature values of Al, Co added YGdFe₁₇ compounds.

Compound	a (Å)	c (Å)	V (Å³)	M_s (emu/g)	T_C (K)
YGdFe ₁₇	8.55	8.38	612.6	82	476
YGdFe ₁₇ Al	8.67	8.50	638.9	93	325
YGdFe ₁₆ CoAl	8.61	8.44	625.7	113	542

FIGURES

Fig. 1 X-ray diffraction patterns of $\text{YGdFe}_{17}\text{M}$ compoundsFig.2. Variation of M_s in $\text{YGdFe}_{17}\text{M}$ compounds

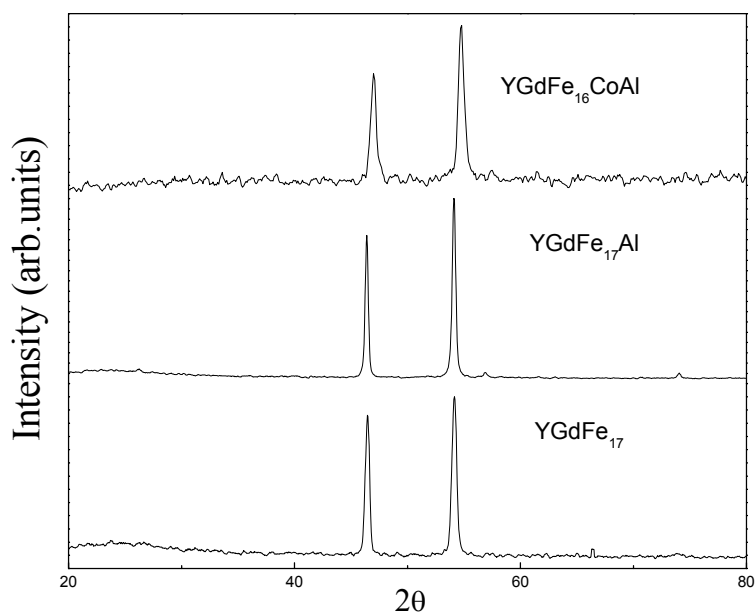


Fig.3 X-Ray diffraction patterns of aligned sample powders YGdFe₁₇M compounds

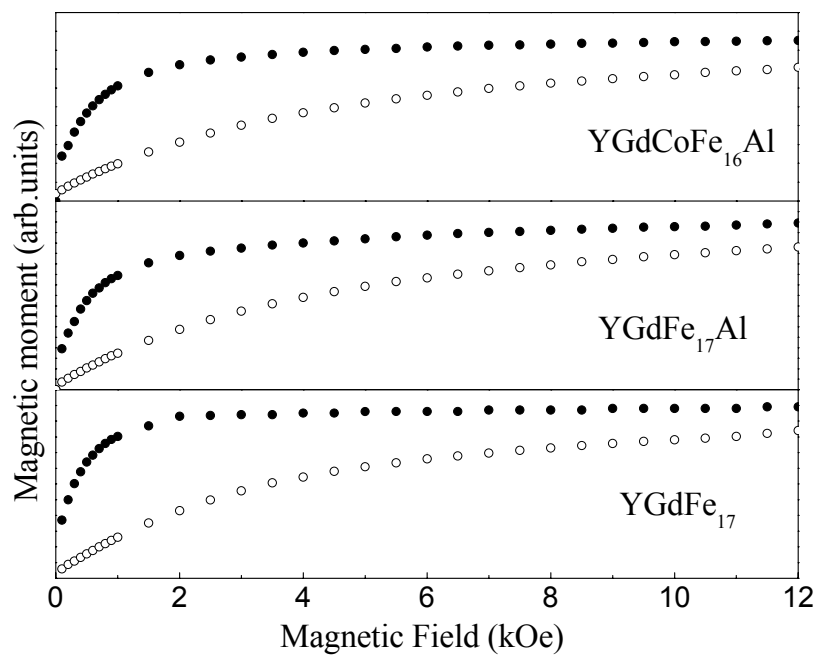


Fig.4 Change in anisotropy in YGdFe₁₇M compounds