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LETTER TO THE EDITOR

The non-universality of the relation between the Néel temperature and the lattice parameter in γ-Fe–Mn host antiferromagnetic alloy

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Abstract. The effects of alloying elements Al, Cr, Si, V, Ni and Co on the Néel temperatures and lattice parameters of γ-Fe–Mn alloys are analysed. Our experimental results fail to confirm the universal relation between Néel temperature and lattice parameter proposed by Adachi *et al*. It is suggested that the Néel temperature is not a unique and monotonic function of the lattice parameter for γ-Fe–Mn host alloys.

Adachi *et al* [1] plotted the Néel temperatures against the lattice parameters for some γ-Fe-like antiferromagnetic alloys including γ-Fe, Fe–Ni–Cr, Co–Mn, Co–Mn–Fe, Fe–Ni–Mn and γ-Fe–Mn, as shown in figure 1; consequently they suggested that there is a universal relation between Néel temperatures and lattice parameters for these FCC antiferromagnetic alloys, i.e. Néel temperatures increase with increasing lattice parameters, and then they inferred that magnetic interaction depends on the interatomic distance regardless of constitutional elements for those alloys (mean outer shell electron concentrations (e/a) of alloys in figure 1 are between 7.5 and 8.4). Endoh and Ishikawa [2] suggested that the antiferromagnetism of γ-Fe–Mn can be classified into three groups according to the composition: γ-Mn-like for the Mn rich side (0–30 at.% Fe); γ-Fe–Mn-like for the intermediate region (40–80 at.% Fe) and γ-Fe-like for the Fe rich side (80–100 at.% Fe). The compositions of γ-Fe–Mn alloys in figure 1 are not indicated, but, according to their Néel temperatures and lattice parameters [2], they can be estimated to be γ-Fe–(20–50 at.%) Mn, which belong to the γ-Fe–Mn-like antiferromagnetism group. The purpose of the present letter is to investigate the relation between Néel temperature and lattice parameter for γ-Fe–Mn alloys containing Al, Cr, Si or V so as to verify the monotonic relation between them proposed by Adachi *et al* and comprehend the effect of solute elements on the antiferromagnetism of γ-Fe–Mn host alloy from a different aspect.

Our experimental results of Néel temperatures and lattice parameters on γ-Fe–Mn host alloys in recent years are listed in table 1. The alloys tested contain 19–33 at.% Mn, and transition elements Cr or V and non-transition elements C, Al or Si are soluted to replace Fe atoms, which means constant Mn content in each alloy system. Figure 2 shows the relation between Néel temperatures and lattice parameters of the above-mentioned alloys. For the γ-Fe–Mn–Cr and γ-Fe–Mn–Al–V alloy systems, as the Cr or V content increases, the lattice parameter increases, but the Néel temperature decreases, and the effect of V is larger than that of Cr. Also as the Al content in γ-Fe–Mn–Al alloy increases, the lattice parameter increases, but the Néel temperature decreases dramatically. Only the Néel

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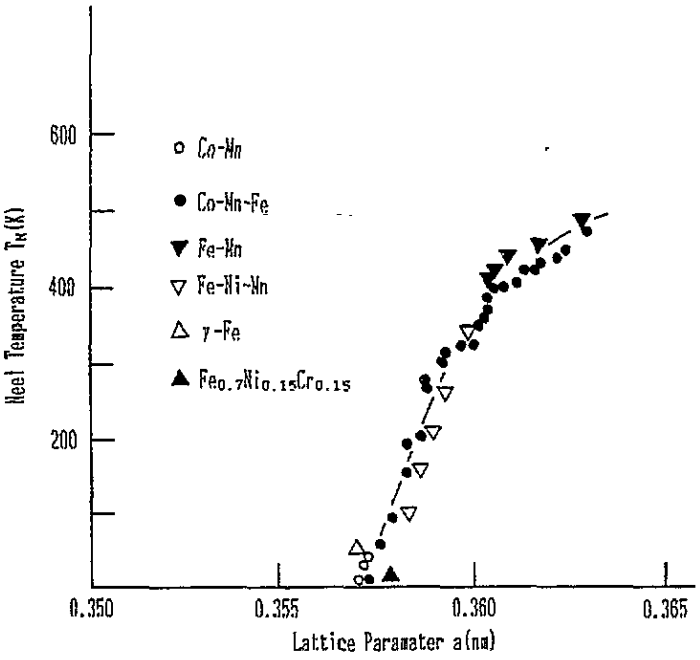

Figure 1. Néel temperatures against lattice parameters for the γ-Fe-like antiferromagnetic alloys (from figure 8 of [1]).

temperature of γ-Fe–Mn–Si alloy decreases along with decreasing lattice parameter, as the Si content increases, but it still has a deviation from the curve plotted by Adachi *et al* [1]. Figure 3, which is the merging of figures 1 and 2, indicates that the experimental results of the present paper do not agree with the inference proposed by Adachi *et al*.

In order to analyse the result of figure 3, it can be conducive to consider the influence of solute elements on the lattice parameters and Néel temperatures of γ-Fe–Mn alloys. For the γ-Fe–Mn alloys replacing Fe atoms by Al, Cr or Si, whose compositions are mostly the same as that of the present letter, the experimental result measured by Tian Xing and Zhang Yansheng [3] showed that the lattice parameter of γ-Fe–Mn alloy increases linearly as the solution of Al or Cr increases but decreases linearly as the solution of Si increases. The sign and amplitude of the lattice parameter's change depend on the sign and amplitude of the atomic radius's difference between the solute atom and the Fe atom. Investigation by Zhang Yansheng [4–6] has shown that the effects of solutes such as Al, Cr, Si, Ge, V and Mn on the paramagnetic–antiferromagnetic transition and the Néel temperature of the γ-Fe–Mn alloy mainly depend on their outer shell electronic structures and their interactions with the energy band of the matrix. The mean outer shell electron concentrations of alloys are also concerned. In the composition range of his investigation, the Néel temperature decreases linearly along with decreasing mean electron concentration. For example, Al($3s^2 3p^1$) and Si($3s^2 3p^4$), which have similar outer shell electronic structure, weaken the itinerant electron characteristic of γ-Fe–Mn antiferromagnetism and induce or enhance the formation of localized magnetic moment on the Fe sites as well as reducing the stability of the antiferromagnetic state. The extent of the effect of Al or Si on the temperature dependence of the magnetic susceptibility, the Néel temperature and the associated anomaly of resistivity are also similar. Al (the atomic radius is 0.1432 nm, larger than that of

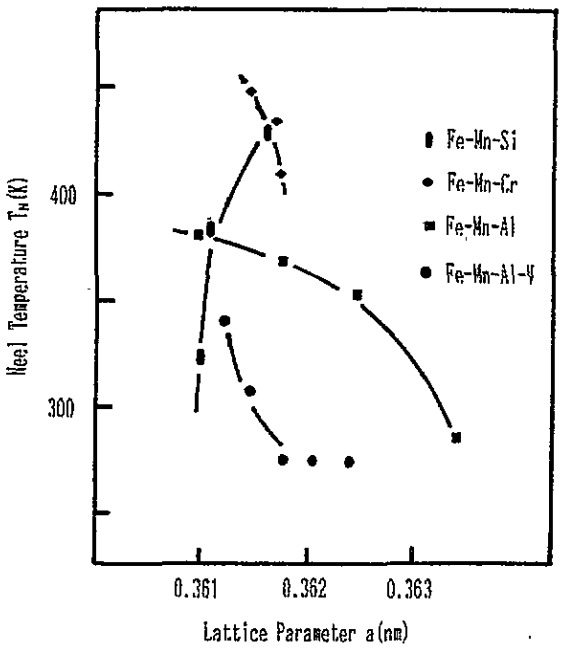

Figure 2. Néel temperatures against lattice parameters for the γ-Fe–Mn host alloys of the present investigation.

Table 1. Chemical compositions (at.%), lattice parameters (nm) and Néel temperatures (K) of alloys tested.

Mn	C	Al	Cr	Si	V	Fe	a (nm)	T_N (K)
25.59	0.69	1.10		0.31		bal.	0.361 01	380
24.47	0.67	4.45		0.10		bal.	0.361 75	368
24.80	0.68	6.27		0.15		bal.	0.362 46	353
23.78	0.66	9.77		0.15		bal.	0.363 39	284
31.63	0.98			0.25		bal.	0.361 44	448
30.92	0.92		3.50	0.25		bal.	0.361 69	433
30.98	0.96		5.21	0.25		bal.	0.361 74	408
32.55	0.64			2.13		bal.	0.361 61	428
30.62	0.67			5.31		bal.	0.361 07	383
30.38	0.79			8.67		bal.	0.360 98	323
19.54	0.29	4.97		0.10		bal.	0.361 21	340
19.27	0.72	4.89		0.10	0.53	bal.	0.361 46	307
18.97	1.34	4.96		0.11	1.06	bal.	0.361 78	273
19.04	1.73	4.85		0.10	1.54	bal.	0.362 06	273
19.07	2.00	4.84		0.10	2.31	bal.	0.362 41	273

Fe (0.1241 nm)) obviously increases the lattice parameter of the γ-Fe–Mn alloy while Si (the atomic radius is 0.1176 nm, smaller than that of Fe (0.1241 nm)) reduces the lattice parameter of the γ-Fe–Mn alloy; nevertheless both Al and Si reduce its Néel temperature (−11.5 K/at.% for Al and −13.2 K/at.% for Si) [7]. Antiferromagnetic Cr has no or little localized magnetic moment in the γ-Fe–Mn alloy, therefore it has less effect on the temperature dependence of the susceptibility and resistivity of the γ-Fe–Mn alloy; its effect

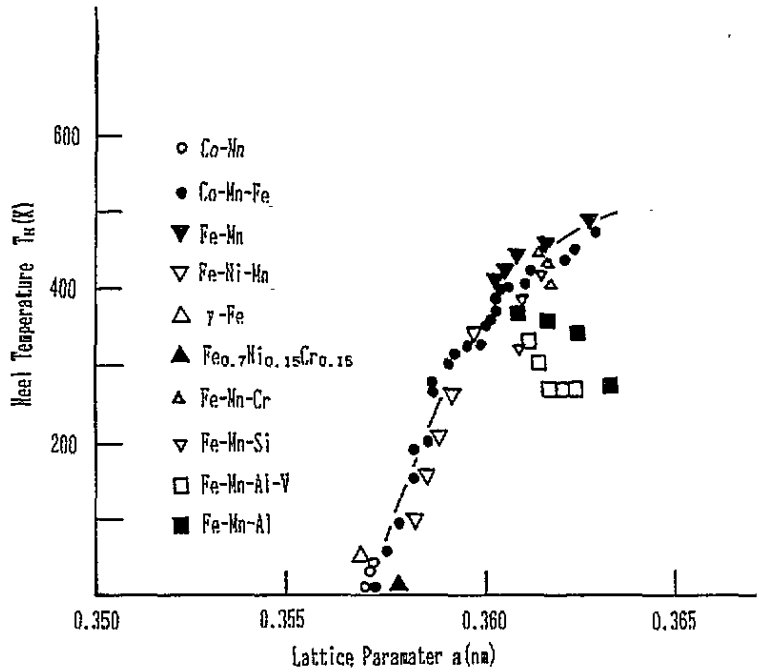

Figure 3. Néel temperatures against lattice parameters for various FCC antiferromagnetic alloys (merging of figures 1 and 2).

on the Néel temperature of the γ-Fe–Mn alloy is only -3.9 K/at.%. V has no obvious influence on the temperature dependence of the susceptibility of γ-Fe–Mn and γ-Fe–Mn–Al alloys, but drastically reduces their Néel temperatures. This puzzling problem may be related to the fact that V increases the antiferromagnetic resistivity of these alloys at low temperature [8]. As far as γ-Fe–Mn–Ni and γ-Fe–Mn–Co alloys are concerned, Ni or Co weakens the stability of the antiferromagnetism and reduces the Néel temperature of the alloys as a result of formation of localized magnetic moment on Ni or Co sites.

For the γ-Fe–Mn alloy, as the Mn content increases the Néel temperature and lattice parameter increase simultaneously, so the result obtained by Adachi *et al* is that the Néel temperature increases along with increasing lattice parameter for the γ-Fe–Mn binary alloy in figure 1. However as stated above, in contrast to Mn, other solutes, such as Ni, Co, V, Al, Si, Cr or Ge, reduce the Néel temperature of the γ-Fe–Mn alloy, no matter whether they increase the alloys lattice parameter or not, and no matter which atom (Fe or Mn) is replaced. Other alloy systems such as $Co_{1-x}Mn_x$ [9], $Co_{1-x}(FeMn)_x$ and $(CoFe)_{1-x}Mn_x$ [10] and $Fe_{65}(Ni_{1-x}Mn_x)_{35}$ [11], which were plotted in figure 1, can be analysed as follows: atomic radii of Co (0.1253 nm) and Ni (0.1246 nm) are smaller than that of Mn (0.1366 nm); an increase of x means that Mn atoms replace Co or Ni atoms, then the Néel temperature and the lattice parameter increases simultaneously; otherwise, as x decreases, i.e. Co or Ni atoms replace Mn atoms, both Néel temperature and lattice parameter decrease. However if Co or Ni atoms replace Fe atoms in γ-Fe–Mn–Ni or γ-Fe–Mn–Co alloys, then the alloy's lattice parameter will increase but the Néel temperature will decrease. This is just the same case as the γ-Fe–Mn–Al, γ-Fe–Mn-Al–V and γ-Fe–Mn–Cr alloys of the present letter. Therefore Adachi *et al*'s relation between the Néel temperature and the lattice parameter is only suitable for γ-Fe–Mn host alloy systems under their specific composition condition.

According to the above discussion, it can be suggested that the Néel temperature of the γ-Fe–Mn host alloy mainly depends on the atomic outer shell electronic structures of constitutional elements and their interactions with the matrix, that the lattice parameter is related to the atomic radii of constitutional elements and that the Néel temperature is not a unique and monotonic function of the lattice parameter. The relation between Néel temperature and lattice parameter proposed by Adachi *et al* appears invalid for γ-Fe–Mn host alloys.

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References

[1] Adachi K, Matsui M and Mitani S 1973 *J. Phys. Soc. Japan* **35** 426
[2] Endoh Y and Ishikawa Y 1971 *J. Phys. Soc. Japan* **30** 1614
[3] Tian Xing and Zhang Yansheng 1991 *Mater. Sci. Prog.* **5** 48 (in Chinese)
[4] Zhang Yansheng 1985 *Acta Metall. Sinica* **21** A 295 (in Chinese)
[5] Zhang Yansheng 1988 *J. Phys. F: Met. Phys.* **18** L229
[6] Zhang Yansheng and Zeng Hongbin 1990 *J. Phys.: Condens. Matter* **2** 2015
[7] Zhang Yansheng 1988 *Mater. Sci. Prog.* **2** 56 (in Chinese)
[8] Zhu Naiping and Zhang Yansheng 1989 *Mater. Sci. Prog.* **3** 147 (in Chinese)
[9] Matsui M, Ido T, Sato K and Adachi K 1970 *J. Phys. Soc. Japan* **28** 791
[10] Matsui M, Sato K and Adachi K 1973 *J. Phys. Soc. Japan* **35** 419
[11] Shiga M 1967 *J. Phys. Soc. Japan* **22** 539