Magnetic structure of an Fe–Pd–Rh alloy

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Martensitic phase transition in an aged Fe–Pd–Rh alloy was studied using transmission electron microscopy (TEM) and x-ray diffraction. Both TEM and x-ray diffraction reveal the appearance of an intermediate structure between the fcc→L10 martensitic transformation. The intermediate phase, denoted L1m, has a monoclinic structure with lattice parameters of a=3.193 Å, b=3.684 Å, c=3.141 Å, and β=92.042°, and the normal L10 martensitic phase has an ordered structure with lattice parameters of a=3.876 Å, c=3.684 Å, and c/a=0.950, as confirmed by TEM and x-ray diffraction. © 2007 American Institute of Physics. [DOI: 10.1063/1.2712174]

Martensitic transformation has recently been more actively studied because the ferromagnetic shape memory effect (FSME) has been found in relation to martensitic transformation. The Fe–Pd–Rh alloy with the FSME is now a candidate for practical use as functional materials. Therefore, understanding the phase separation on martensitic transformation is very important in order to obtain the technical information necessary for developing the alloy for a smart material.1 The primary purpose of the present study is to provide insight into the phase transformation and magnetic property of the aged Fe–30Pd–4Rh ferromagnetic alloy by use of selected area diffraction patterns (SADPs) of transmission electron microscopy (TEM), x-ray diffraction, and a superconducting quantum interference device (SQUID). There is evidence of an intermediate L1m monoclinic structure which should be formed between the fcc→L10 martensitic transformation. Observations suggest that the observed intermediate L1m phase is tentatively the adaptive martensite.

An essential TEM SADP with zone axis [1 1 1]L10 of the Fe–30Pd–4Rh alloy solution treated (ST) at 950 °C for 1.5 h and quenched in water is shown in Fig. 1(a). (hkl denotes L10 structure). On the basis of the diffraction pattern analysis, a faint superlattice reflection at the {101}L10 position can be seen from the micrograph, an indication that the as-quenched γfcc phase separation into the L10 structure should be a weak first ordering reaction.2 The ordering reaction begins during the quench. Due to the appearance of the faint superlattice reflection in the SADP, the L10 should be reasonably inferred as a first ordered structure. Figure 1(b) is a dark field (DF) image formed using the (202)L10 reflection corresponding to Fig. 1(a). In this image, the first ordered L10 structure that is in bright contrast with a twinned structure (tetragonal) can be distinctly observed in the early phase transition.
The SADP of the TEM micrograph taken from the alloy ST and then thermally aged at 550 °C for 110 h is shown in Fig. 2(a), in which the zone axis reveals the [2 1 3]Lm, ||[0 0 1]L10 (hkl denotes the ordered L10 phase; hkl denotes the monoclinic L1m structure). By calculating the x-ray diffraction d spacing in association with the SADP image measurements, it is found that the adaptive L1m phase has a monoclinic structure with lattice parameters of \(a = 3.193 \, \text{Å}, b = 3.684 \, \text{Å}, c = 3.141 \, \text{Å}, \) and \(\beta = 92.042^\circ\), and the ordered L10, a martensitic structure with lattice parameters of \(a = 3.876 \, \text{Å}, c = 3.684 \, \text{Å}, \) and \(c/a = 0.950\). Figure 2(b) is a DF image formed using the adaptive (101)Lm monoclinic reflection corresponding to Fig. 2(a). The DF image of Fig. 2(b) reveals that the intermediate L1m monoclinic phases are comprised of the periodic alternating microtwins and antiphase boundaries (APBs). These planar faults strongly support the mechanism of coercivity in the aged Fe–Pd–Rh alloy system; it has tended to favor microtwins and APBs pinning the magnetic domain wall, which has been illustrated as a possible source of magnetic hardening.3–5 For further confirmation of the existence of two phases in the aged alloy, a high resolution TEM (HRTEM) image [Fig. 3(a)] taken from the same specimen shows the presence of the monoclinic L1m structure with an ordered L10 phase, and the APBs (i.e., the faint black curved image) in the matrix, as indicated by an arrow. Due to the appearance of the APBs, the aged L10 phase should be reasonably inferred as a second ordered structure, and the APBs pinning the magnetic domain wall are further demonstrated as a possible source of magnetic hardening of the alloy after ST and then thermally aging. By careful measurements of the lattice space, it is found that the d spacing of the monoclinic L1m structure is 2.2 Å, and the ordered L10 phase is 2.6 Å; therefore, the plane can be reasonably inferred to be (101)L1m and (101)L10, respectively. The corresponding SADP image of Fig. 3(a) is shown in Fig. 3(b), revealing the zone axis [1 0 1]L10, [1 0 1]L1m (hkl denotes the ordered L10 phase; hkl denotes the monoclinic L1m structure). The two phases’ reflections are clearly shown in the SADP image.

From TEM study, it is tentatively inferred that the phase transition sequences in the alloy system are as follows: \(\gamma_{\text{FCC}}\) quenched transition → \(\gamma_{\text{FCC}} + L1_m + \text{first ordered } L1_0\) structure, and thermally aged the \(\gamma_{\text{FCC}} + L1_m + \text{first ordered } L1_0\) phase → \(\alpha_{\text{bcc}} + L1_m + \text{second ordered } L1_0\) structure. The phase transformation mechanism includes (a) \(\gamma_{\text{FCC}} \rightarrow \gamma_{\text{FCC}} + L1_m + \text{first ordered } L1_0\) structure, which is a displacive transition (diffusionless) through atoms rapidly shifting to form a new atomic arrangement that in displacive transition occurs rapidly. (b) By aged the \(\gamma_{\text{FCC}} + L1_m + \text{first ordered } L1_0\) phase...
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