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Effects of particle and grain sizes on martensitic transformation in an Fe–30.5 at.%Ni alloy

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ABSTRACT

We have investigated martensitic transformation in micrometer-sized single and poly crystalline particles of an Fe–30.5 at.%Ni alloy by their temperature dependences of magnetic susceptibility measurement and X-ray diffraction. Following results are obtained: (1) poly crystalline particles show a “so-called” athermal martensitic transformation and M_s temperature decreases from 215 K to 151 K with decreasing particle size from 1000 μm (average grain size is 250 μm) to 18 μm (average grain size is 3.7 μm). The single crystalline particle with its size of 7.6 μm also shows a “so-called” athermal martensitic transformation as in the poly crystalline particles, but its M_s temperature decreases drastically (M_s = 77 K). (2) The single crystalline particle with its size of 4.6 μm has no M_s temperature and shows a “so-called” isothermal martensitic transformation. However, M_s temperature appears again in this particle when we introduce grain boundaries and dislocation in the particle by sintering and/or deforming. Considering these results, we conclude that the suppression of martensitic transformation in the micrometer-sized particles of an Fe–Ni alloy is due to the lack of lattice defects for the nucleation, such as grain boundary and dislocation. Furthermore, the single crystalline particle with its size of 4.6 μm shows the athermal martensitic transformation again under the magnetic field and its chemical driving force of the martensitic transformation is estimated to be about 2.0 kJ/mol.

1. Introductions

It is well known that the martensitic transformation appearing in many Fe-, Cu- and Ti-based alloys and ceramics is one of the most typical first order structural phase transitions without atom diffusion, and its characteristics has been studied from the viewpoints of thermodynamics and crystallography because of their ability to provide desirable mechanical and functional properties such as high strength, shape memory effect and pseudoelasticity [1–4]. According to previous studies, martensitic transformation is influenced by alloy composition, character of grain boundary and external fields such as magnetic field, uniaxial stress and hydrostatic pressure [5–10]. The specimen size also affects the martensitic transformation and has been investigated in micrometer-sized alloy specimen by some researchers. However, these studies have been examined using only poly crystalline specimens [11,12]. Therefore, it is difficult to clarify between the effect of specimen size and the effect of grain boundary on martensitic transformation. In order to make this problem clear, we prepare the micrometer-sized poly and single crystalline specimens of an Fe–30.5 at.%Ni alloy and investigate their martensitic transformation behavior.

2. Experimental procedure

We prepared the mother alloy of an Fe–30.5 at.%Ni by melting high purity pure metals. The poly and single crystalline particles of an Fe–30.5 at.%Ni alloy were made using the mother alloy by a gas atomizing method and then the fabricated micrometer-sized powder was separated into four sizes by using an air current instrument and meshes. We also prepared a poly crystalline bulk specimen with its grain size of 250 μm and a single crystalline bulk specimen with its size of 1 mm cube using a part of the mother alloy.

Microstructure of each specimen was observed by a scanning electron microscope (SEM). The parent and martensite phases of each specimen are confirmed as the f.c.c. phase and the b.c.c. phase by an X-ray diffraction measurement, respectively. In order to investigate the transformation behavior and the magnetic property in the present specimens, we investigate a magnetic susceptibility as a function of temperature by a SQUID magnetometer at temperatures between 5 and 350 K. In order to introduce lattice defects into particles, we performed the sintering and/or the deforming for the single crystalline particle with its size of 4.6 μm. The sintering temperature was 973 K and sintering times were 300, 600 and 3600 s. The deforming was performed by a WC mold and the pressures of pressing were 50 and 100 MPa.

3. Results and discussion

In order to determine the specimen size and grain size, SEM observation has been performed and the results are shown in Fig. 1.

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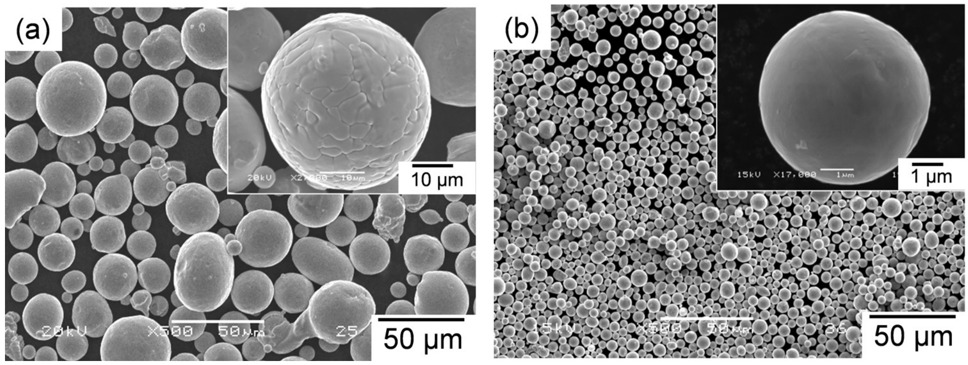

Fig. 1. Micrographs of particles in an Fe–30.5 at.%Ni alloy obtained by SEM observation. (a) and (b) are results of poly crystalline particle with its size of 25 μm (average grain size is 6.7 μm) and that of single crystalline particle with its size of 7.6 μm, respectively. The insets are magnified photos of (a) and (b).

Table 1
Average particle size, particle state and average grain size in as-atomized powder of an Fe–30.5 at.%Ni.

Alloy system	Fabrication method	Average particle size	Particle states	Average grain size
Fe–30.5 at.%Ni	Gas-atomizing method	25	Poly	6.7
		18	Poly	3.7
		7.6	Single	×
		4.6	Single	×

As seen inset figure in Fig. 1(a), the particle has a spherical shape with grain boundaries and, that in (b), the particle has also a spherical shape and has a smooth surface without grain boundary. So, it is concluded that the particle in (a) is a poly crystal and that in (b) is a single crystal. The average particle size and the grain size for each specimen are summarized in Table 1, where the average particle size and grain size are determined by a line segment method using results of SEM observations.

In order to investigate the magnetic property and the transformation temperature for each specimen, we measure its magnetic susceptibility as a function of temperature and the results are shown in Fig. 2, where (a)–(c) represent results for poly crystalline particles and (d)–(f) for single crystalline particles. It should be noted in the figure that the magnetic susceptibilities in both poly and single crystalline particles show a rapid increase at the temperature indicated with an arrow on their cooling curves except for the single crystalline particle with its size of 4.6 μm shown in (f). According to the previous study [13], this temperature corresponds to the martensitic transformation start temperature (M_s) from the f.c.c. phase to the b.c.c. phase for each specimen. Then, we summarize the relation between the M_s temperature and the specimen size and/or the grain size in all the particles used in the present study,

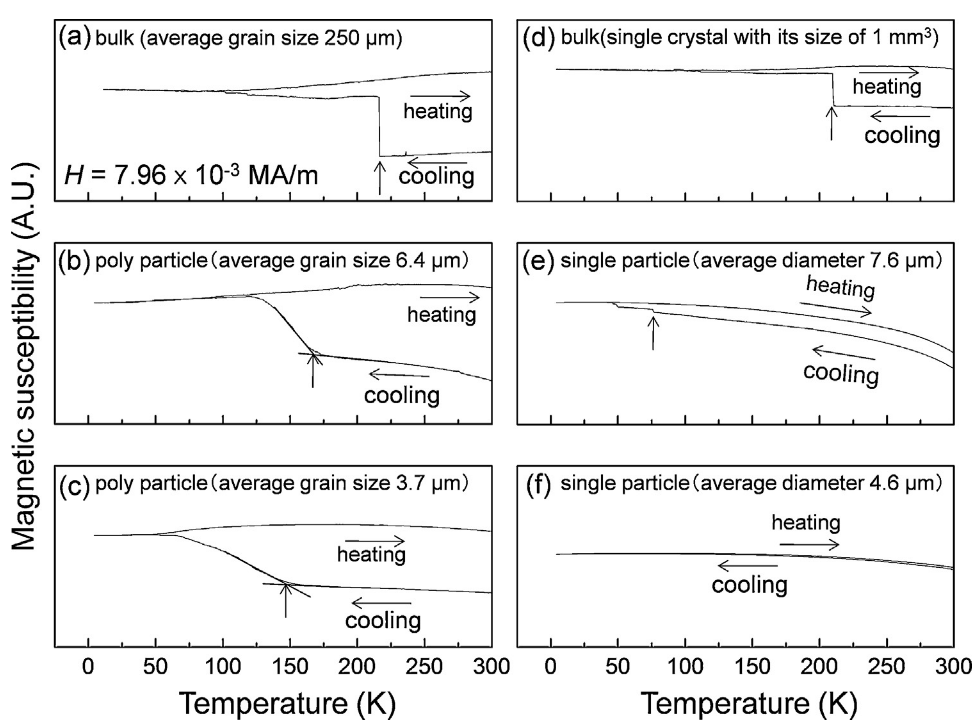

Fig. 2. Temperature dependence of magnetic susceptibility for each specimen in an Fe–30.5 at.%Ni alloy. Left figures are the results of poly crystalline particles and right figures are those of single crystalline particles.