EFFECTS OF MAGNETIC FIELD ON SHAPE EVOLUTION OF IRON-COBALT PARTICLES IN A COPPER MATRIX

08D26060 Chiharu KANNO

Kato • Onaka • Fujii Laboratory, Department of Innovative and Engineered Materials, Tokyo Institute of Technology.

Introduction
Processing in a high magnetic field has been found to be a promising method to control microstructures and properties of materials [1]. Fujii et al. reported that small ferromagnetic fcc Co particles embedded in a Cu matrix elongate in a direction parallel to applied magnetic field during ageing and explained the results by the concept of the minimization of the magnetostatic energy of the Co particles [1]. Although they discussed the growth process of the ferromagnetic particles under the magnetic field parallel to the [001] direction, it is not clear as to whether the particles always grow along the direction of the applied magnetic field other than [001]. One of the purposes of the present study is to reveal the orientation dependence of particle elongation during ageing under the magnetic field.

Experimental
Cu-0.83at%Fe-1.37at%Co single crystals were grown by the Bridgman method using a seed crystal. The single crystals were solution treated at 1323K for 2h and quenched into water. The solution-treated specimens were aged at 993K for 2h to 24h under the magnetic field of 10T parallel to either the [001] or the [011] direction. The specimens were also aged at 993K for 2h to 24h without magnetic field. The magnetic anisotropy was examined by measuring magnetic torque around the (100) plane under a magnetic field of 1.57T using a Naruse TM-II torque meter. The microstructures of aged specimens without magnetic field were observed in a JEOL JEM2011 transmission electron microscope (TEM) at an accelerating voltage of 200kV.

Results
Figure 1(a) shows the magnetic torque curve of a specimen aged at 993K for 2h without magnetic field. It is to be noted that the torque curve in Figure 1(a) is nearly sinusoidal. Figures 1(b)-(f) and 2(a)-(d) show magnetic torque curves of specimens aged at 993K for 2h to 24h under the magnetic field of 10T parallel to the [001] and [011] directions, respectively. It can be seen that the magnetic torque curves of specimens aged under the magnetic field are remarkably different from the curve shown in Figure 2(a). The amplitude of the curves increases as ageing time increases.

Discussion
The total shape-dependent energy of a precipitated fcc Fe-Co particle in a Cu matrix is composed of the interface energy, the elastic strain energy and the magnetostatic energy during ageing under the magnetic...
In this study, the shape stability of a single fcc Fe-Co particle is discussed by considering the total energy variation due to the shape change from a sphere to a prolate spheroid during ageing under the magnetic field. Figure 3 shows the change in the aspect ratio as a function of the particle size $r_{eq}$. The experimental values of $m$ were derived from Figure 1 and Figure 2. In addition, the calculated values were those which give the minimum total energy $\Delta E_t$ as a function of $r_{eq}$. It is encouraging to find that the experimental results are in good quantitative agreement with the calculated results for both [001] and [011] elongations. However, the experimental values of $m$ are slightly larger than the calculated values in each case. This is reasonably understood if we consider the size distribution of the Fe-Co particles. As discussed above, the magnetostatic energy is proportional to the volume of the particle. Since the particle size is not uniform in the aged sample for torque measurement, the dominant contribution of the particles with sizes larger than the average size to the experimental values of $m$ can be expected. As a result, the experimental values of $m$ may become larger than the calculated values based on the assumption of the uniform size distribution. Only the elastic strain energy $\Delta E_{el}$ depends on the elongation directions of the particle. Therefore, the dependence of the total energy $\Delta E_t$ on the magnetic field direction solely comes from the cubic anisotropy of the elastic constants.

Figure 3 Particle size dependence of the calculated aspect ratio to give the total energy minimum.

Conclusions

Elongation of spherical fcc Fe-Co particles in a Cu matrix during ageing under applied magnetic field of 10T was investigated. The magnetic anisotropy of aged specimens were examined by measuring magnetic torque around the (100) plane. The experimental magnetic torque curves were analyzed by considering magnetocrystalline anisotropy and magnetic shape anisotropy. The following results have been obtained.

1. Precipitated fcc Fe-Co particles are elongated in the direction parallel to the magnetic field, either [001] or [011], when the particles are aged under the magnetic field.

2. The changes in the aspect ratio of the fcc Fe-Co particles depend on the direction of the magnetic field.

3. As a result of the quantitative analysis considering the interface energy, the elastic strain energy and the magnetostatic energy, it is found that the above conclusion (1) can be explained by considering the minimization of the magnetostatic energy of fcc Fe-Co particles, and the conclusion (2) can be understood in terms of the elastic stability that depends on the shape and elongation direction of Fe-Co particles.

Future work

It has been well known that strong magnetic field affects phase stability in ferromagnetic material. As future work, the effects of applied magnetic field on solid solubility of Fe and Co in a Cu matrix will have been investigated. Solution treated Cu-1.34 at% Co-0.76 at% Fe alloy polycrystals were aged at 973K for 4h with a magnetic field of 10T. The solid solubility of Fe and Co was estimated by measuring the saturation magnetization using a vibrating-sample magnetometer. The values of total solubility of Fe and Co in the aged specimens with and without applied magnetic field were found to be 0.35 at% and 0.45 at%, respectively. The decrease in solid solubility during the magnetic ageing can be explained by the magnetic field-induced absorption of Fe and Co atoms into the Fe-Co particles.

Reference


Publications