PREFERENTIAL ALIGNMENT OF COHERENT PRECIPITATES UNDER THE INFLUENCE OF TETRAGONAL ELASTIC INTERACTIONS

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Herein a phenomenon which we term the self-stress orienting phenomenon is defined and documented in three precipitation systems, namely, Aℓ-Cu, Cu-Be and Ni-V. In each of these systems a metastable coherent phase with a tetragonal strain field forms. Initially there are equal numbers of each of the variants and the distribution is random. However after coarsening begins, one of the variants begins to dominate the local microstructure, in that the other two variants begin to preferentially dissolve. The phenomenon occurs in bulk materials as well as thin films. Details of the phenomenon are presented and discussed.

The formation of second phase particles from a supersaturated solid solution is often considered to be composed of the stages nucleation, growth and coarsening. Coarsening has been the topic of many investigations. Of particular interest has been the elucidation of the kinetics of coarsening. Several authors (1-3) have arrived independently at the same equation that governs coarsening; in particular, the average size of the coarsening phase has been shown to be proportional to the one-third power of time. Microstructural features of coarsening have also been the topic of investigation. For example, Ardell and Nicholson (4) have reported that in the Ni-Aℓ system, where the precipitate originally forms uniformly throughout the Ni matrix, elastic interactions between particles during coarsening are responsible for subsequent alignment of the cuboidal precipitates along the elastically soft ⟨100⟩ directions of the fcc Ni-based matrix.

Other interesting microstructural features have also been reported. The shape of precipitates in a single crystal matrix has been observed to change during coarsening when a load was applied to the crystal (5). Also, the dominance of a given variant of precipitates with tetragonal symmetry has been shown to be dependent on the direction of the load applied to Aℓ-Cu crystals (6).

Herein, we report on yet another microstructural feature of the coarsening process. Several systems in which a metastable, tetragonal second phase forms have been investigated (Aℓ-Cu, Cu-Be, Ni-V). In each of the systems the three variants of the precipitates are initially uniformly distributed within the matrix grains. However, during coarsening one variant in a given region predominates and becomes virtually the only one present in that region. We attribute this preference of a given variant to the self-stress interaction among the precipitates (as opposed to an applied stress) and term the process the "Self-Stress Orienting Phenomenon" (SSOP). Microstructures demonstrating the phenomenon from the various systems investigated will be presented.

Experimental Procedure

Binary alloys of Aℓ-4 w/o Cu, Cu-2 w/o Be and Ni-19 a/o V were cold rolled, solution treated and aged at various temperatures to obtain the desired precipitates. See reference (7) for more specific details. Of special importance is the fact that the alloys were all quenched directly to the aging temperature from the solutionizing temperature.

Transmission Electron Microscopy (TEM) was performed in a JEOL 100C electron microscope operating at 100 KV. A double tilt stage which permitted $\pm$ 60° rotation along the X axis and $\pm$ 30° tilt along the Y axis was used. Bright Field (BF), Conventional Dark Field (CDF), Weak Beam (WB) and Selected Area Diffraction (SAD) techniques were employed.

Experimental Results and Discussion

Aℓ-4% Cu Alloys

Samples DQ to 160°C (433 K) and aged for one hr. exhibited uniformly distributed G.P. zones. The distribution of precipitates remained similar during isothermal aging up to 11 hr. after which two different distributions of θ" precipitates were observed (Figures 1(a) and (b)). Longer isothermal aging treatments resulted in a more pronounced difference in the distribution of θ" precipitates (Figures 1(c) and (d)).

The respective pairs of DF micrographs of Figure 1 were obtained from the same region of a given grain. Therefore, the distribution of the variants of the precipitates is not the same within a given volume. The development of the localized anisotropic distribution of tetragonal orthogonal precipitates is what we call the "Self Stress Orienting Phenomenon" (SSOP). This appears to be due to an elastic relaxation of coherency strains. Since it was important to determine when the SSOP begins, kinetic data were taken on the thickness of θ" precipitates. Measurements were performed on plates imaged in DF, and an average from the 10 thickest plates was obtained. It was observed that the SSOP becomes evident after coarsening begins (7).

Cu-2% Be Alloys

Samples quenched in water at room temperature exhibited faint tweed strain contrast when imaged under a two-beam case in a $\vec{n}$ = [100] orientation. The tweed strain contrast is similar for the two orthogonal $\vec{g}$ vectors. Weak Beam microscopy at this stage of aging revealed the presence of small equiaxed beryllium clusters (8). Longer aging at room temperature resulted in the formation of G.P. zones as revealed by SADP's; e.g., samples aged longer than one day exhibited faint streaks in the $\langle 100\rangle^*$ directions. Samples aged for less than two months showed similar tweed strain contrast. However, after agings of two months, the tweed strain contrast was not equivalent in some grains. SADP's at this stage of aging also reveal the presence of the SSOP. See Figs. 2(a) and (b). Since G.P. zones are present

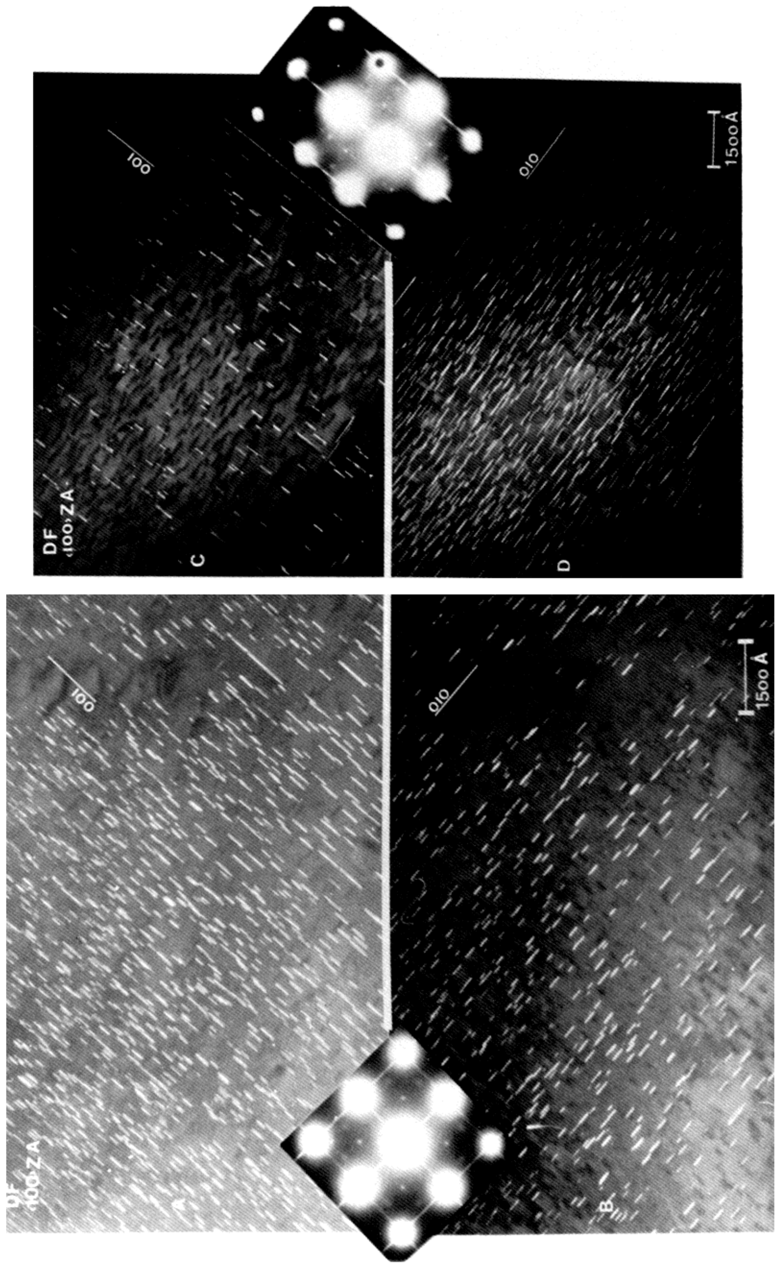
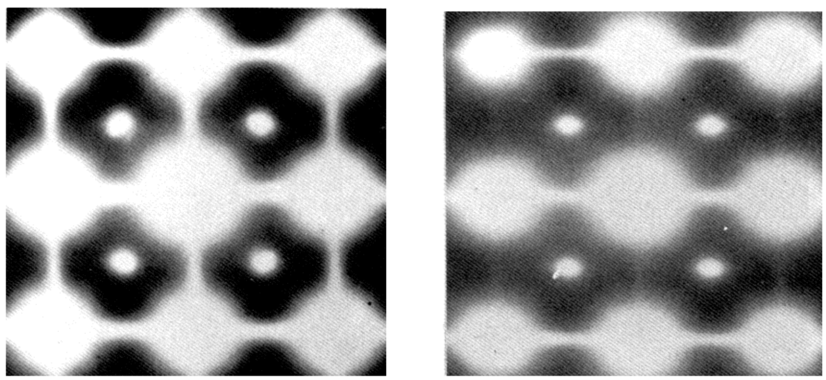
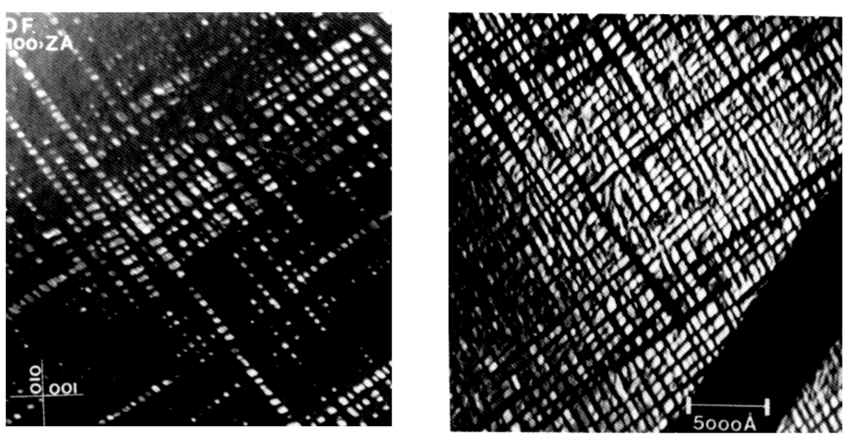


Fig. 1. Aℓ-4 ^{w}/o Cu aged at 160°C: (a) and (b) 11 h., (c) and (d) 49 h. $\vec{n}$ = [100] D.F. from θ''. SSOP can be observed in diffraction pattern.



(a) (b)

Fig. 2. Cu-2 $^{w}/o$ Be alloy, solution treated and quenched to and held at room temperature for 2 months. Both (a) and (b) are from the same grain. In (a) SSOP is not evident, whereas in (b) it is.



(a) (b)

Fig. 3. Ni-19 $^{a}/o$ V alloy, aged at 6.3 h. at 780°C. $\vec{n}$ = [100]. (a) and (b) are D.F. from different variants.

even after 24 hours of aging at this temperature, it appears that the SSOP occurs during the coarsening stage of G.P. zone formation in this alloy as well. The presence of the SSOP when the other metastable phases are present, (e.g. γ' or γ''; see reference 8) can be understood in terms of nucleation at the G.P. zone-matrix interface.

Ni-19% V Alloys

Samples DQ to 780°C (1053 K) for 30 sec. exhibited anisotropic tweed strain contrast, similar to Cu-2% Be alloys. However, individual particles were difficult to resolve by the DF technique. Isothermal aging at 780°C for 1 min. allowed a random distribution of particles to be resolved in DF micrographs. Longer aging time permitted the observation of two different distributions of Ni_3V precipitates aligned along the traces of the {110} planes. Figs. 3(a) and (b) show the development of the SSOP as aging at 780°C proceeds. The DF's were performed making use of superlattice reflections of two DO_{22} variants with their c-axes perpendicular to each other. The occurrence of the SSOP in these alloys is a localized phenomenon. The effect was observed in bulk specimens demonstrating that it is not a "thin foil effect."

The evidence presented here indicates that the preferential evolution of a given variant of precipitates occurs during coarsening, and not during nucleation and growth. Recently, it has been shown that precipitates with a tetragonal strain field may give rise to aligned microstructures via a "reconfiguration mechanism" (9). It was also demonstrated that a specific variant of the tetragonal precipitate dominates during the "reconfiguration" (9). Perovic, Purdy and Brown (10) have also shown that preferential alignment and dominance of a given variant can result, due to the minimization of the elastic interaction energy between adjacent precipitates. They interpret their results in terms of an autocatalytic nucleation process. Their work was performed at small undercoolings where the elastic interaction energy is of the same order of magnitude as the volume free energy change for nucleation. Our work was performed at large undercoolings where the elastic interaction energy is small compared to the free energy change of nucleation. Once the system begins to coarsen, the elastic interaction energy is of the same order of magnitude as the driving force for coarsening, and its effect is observed. See Ref. 11.

Acknowledgments

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