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TEM Study of Morphology and Kinetics of Coarsening of Coherent γ′ Precipitation in a Ni-Ga Alloy under Uniaxial Elastic Compression

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The morphology of γ′ precipitates (Ni_3Al-type, $L1_2$ crystal structure) and coarsening kinetics under applied stress have been extensively studied [1] since it was experimentally shown that the structure of commercial Ni-based superalloys can be altered by directional coarsening, causing significant change of the yield strength [2]. Most of the stress-related experiments on coarsening were conducted on alloys containing a large volume fraction of γ′ precipitates at elevated temperatures and stresses, producing a significant amount of creep. Theoretical predictions and computer simulation studies on morphology and kinetics of coarsening under applied stress suggest that the equilibrium shape of the precipitates depends on a particular combination of the lattice misfit, elastic inhomogeniety of the system, interfacial free energy and the sign of the applied stress [3-7]. Ni-Ga alloys among all other binary Ni-based alloys used to test the theories [8-10], posses the largest lattice mismatch of the phases involved [11]; its elastic moduli have been recently measured [12].

We have investigated the morphology and kinetics of the early stages of coarsening of γ′ precipitates in a Ni-Ga alloy. Twenty cylindrical specimens (average diameter $d = 3.00 \pm 0.01$ mm and length, $l = 3.60 \pm 0.01$ mm) were cut from a bulk single crystal with their major axis parallel to [001]. The specimens were solution treated in an Ar atmosphere at 1220 °C for 45 min, followed by quenching in refrigerated brine. The composition of each cylinder was measured by EDS and only specimens with compositions close to 19.0 ± 0.5 wt % Ga were tested. The specimens were aged for 2, 4 or 8 hours in a specially designed fixture [8] under applied stresses of 50, 100 and 150 MPa at 650 °C. At this temperature, the volume fraction of γ′ in the alloy, estimated using the solvus curve [13], was 0.24 ± 0.04. The applied stresses were chosen to limit deformation in elastic region. Plastic strain was measured for each cylinder and was found not exceed 1% for 150 MPa for the longest aging time. After aging, the cylinders were sliced to make TEM samples. The microstructures of all the samples were examined in the section perpendicular to the applied stress using a JEOL 100CX TEM at an accelerating voltage of 100 kV. Dark-field images using a (001) superlattice reflection were taken to observe the precipitates. The morphology of the γ′ precipitates was characterized by their aspect ratios and a shape parameter that provides a measure of how cuboidal they are. The number of measured precipitates for a particular stress and aging time varied between 250 and 900 particles.

We find that for aging under an applied compressive stress the average size of the precipitates increases with aging time and decreases with applied stress, as shown in Fig. 1. The data also show that the shape parameter is generally unaffected by the stress, while the aspect ratio drops considerably at smaller stress and remains unaffected as the stress increases. In general, it is well known that the aspect ratio of γ′-type precipitates increases and the shape parameter decreases as particles coarsen under stress-free conditions [14,15]. We think that the reason for the significant decrease of the aspect ratio in our experiments is due to an effect of applied stress on coalescence.

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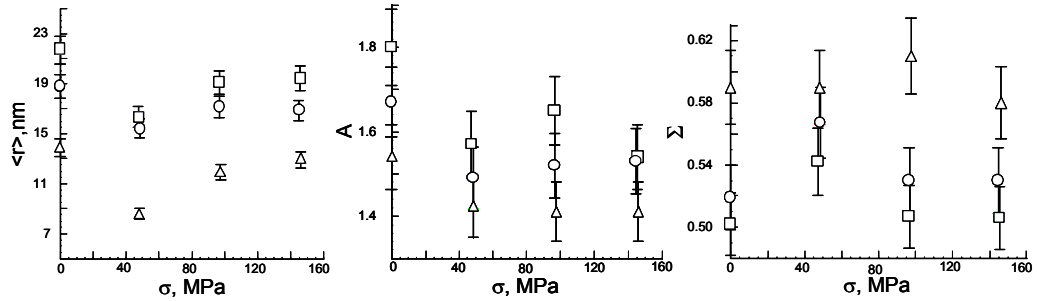
This study shows that γ′ precipitates in Ni-Ga alloys tend to coalesce during coarsening. This result might be understood in the light of recently published data on the elastic moduli of the phases involved [12]. The data show that γ′ precipitates in Ni-Ga alloys are softer, but in Ni-Ge alloys are harder then the matrix. Experimental work on weakly interacting particles in Ni-Ge alloys [10] shows almost no change on the aspect ratio due to the applied stress. The Ni-Ga data on the cube of the average particle size vs. aging time show a significant retardation of coarsening kinetics under applied compressive stress. This result is in good agreement with experimental work on Ni-Al and Ni-Ge alloys [8-10] as well as with the 3D-computer simulations of Gupta et al. [7].



(a) (b) (c)

Fig.1 Effect of the applied stress on the average precipitate radius, (a), aspect ratio, (b), and shape parameter, (c) for the aging times 2 (Δ), 4 (O) and 8 (□) hours.

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