G. W. Bailey, J. M. Corbett, R. V. W. Dimlich, J. R. Michael, N. J. Zaluzec, Eds.
Proceedings of Microscopy and Microanalysis, 1996

TEM STUDY OF PRECIPITATION IN A NiAl-3Ti-0.5Hf SINGLE-CRYSTAL ALLOY

A. Garg, R. D. Noebe, J. M. Howe*, A. W. Wilson* and V. Levit**

NASA Lewis Research Center, Cleveland, OH 44135
* Dept. of Materials Science and Engineering, University of Virginia, Charlottesville, VA 22903
** Dept. of Materials Science and Engineering, University of Florida, Gainesville, FL 32611

Three directionally solidified NiAl single-crystal alloys, NiAl-3Ti, NiAl-0.5Hf and NiAl-3Ti-0.5Hf (at.%), were grown by a Bridgeman technique using high purity alumina crucibles. The ingots were homogenized for 32h at 1644 K followed by aging for 6h at 1255 K and finally furnace cooled under an argon atmosphere. This heat treatment was found to be very effective in dissolving Hf-rich interdendritic particles that were present in the as-cast structure, and at the same time it produced fine second-phase precipitates in the alloy.

Samples for transmission electron microscopy (TEM) were prepared from 3 mm diameter cylinders electro-discharge machined from the heat-treated ingots. Slices sectioned from the cylinders were mechanically ground and electrochemically thinned in a twin-jet Tenupol-3 polisher. Microstructural and energy-dispersive X-ray spectroscopy (EDXS) studies were conducted in a Philips 400T TEM equipped with a double tilt goniometer and a KEVEX Si/Li X-ray detector.

TEM microstructures of the NiAl-3Ti and NiAl-0.5Hf samples were featureless except for the presence of some random dislocations. No homogeneous precipitation was observed in either of the two alloys suggesting that 3 at.% Ti in the first alloy and 0.5 at.% Hf in the second alloy were in solid solution in the NiAl matrix. The microstructure of the NiAl-3Ti-0.5Hf alloy was, however, very different and showed a high density of precipitates. A TEM bright-field image of the alloy close to a $<001>_{NiAl}$ zone-axis is presented in Fig. 1(a). It shows a high density of fine precipitates (size ~ 5-50nm) distributed uniformly throughout the foil, and some coarse precipitates (size ~ 100-700nm) nucleated preferentially on dislocations on $\{100\}_{NiAl}$ planes. The coarse precipitates were always associated with precipitate free zones. The fine precipitates, shown at a higher magnification in Fig. 1(b), clearly exhibited a plate-shape morphology with associated coherency strain. Using EDXS, electron diffraction (Fig. 1(c)) and trace analysis these fine precipitates were identified as Ni_2AlTi Heusler phase ($L2_1$, a = 0.587nm) formed on the $\{100\}_{NiAl}$ planes with a cube-on-cube orientation relationship. Two types of coarse precipitates were found to nucleate on dislocations; edge-on plates (marked T, size ~ 100-250nm) and almost equiaxed precipitates (marked H, size ~ 200-700nm). These precipitates were also found to be Heusler phases; T: Ni_2AlTi, H: Ni_2AlHf ($L2_1$, a = 0.608 nm). Both of these phases are formed by further ordering of the B2 structure of NiAl (ordered BCC, a = 0.289nm) during cooling[1,2]. The lattice misfits of the Ni_2AlTi and Ni_2AlHf phases with the NiAl matrix are 1.5 % and 5.2 %, respectively. Due to large misfit of the Ni_2AlHf phase, a square network of misfit dislocations of spacing ~ 5.6nm was often observed at the Ni_2AlHf/NiAl interface, which made its presence unmistakable and unique.

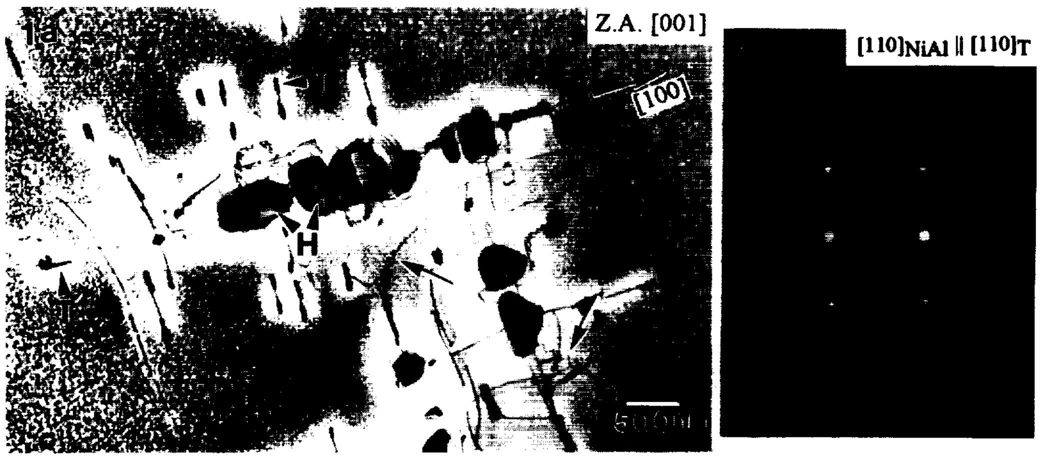
Dislocation segments lying along the $<110>_{NiAl}$ directions were often unstable and found to sharply bend along the $<100>_{NiAl}$ directions, giving them a zigzag appearance (arrows in Fig 1(a)). Preferred nucleation of the Ni_2AlTi precipitates on such segments produced a saw-tooth appearance. In several regions of the foil, a dense precipitation of large Ni_2AlTi plates and some Ni_2AlHf

precipitates were observed along the <110> directions in a $<001>_{NiAl}$ zone-axis (Fig 2). This is believed to be due to preferential nucleation of the Ni_2AlTi precipitates possibly on prismatic dislocation loops.

A high density of fine precipitation as seen in Fig. 1(a) is expected to enhance the creep properties of NiAl single crystals significantly and is under investigation.

References

1. R. D. Field et al., *Scripta Metallurgica*, 23(1989)1469.
2. N. C. Tso and J. M. Sanchez, *MRS Symp. Proc.*, Vol. 133(1989)63.



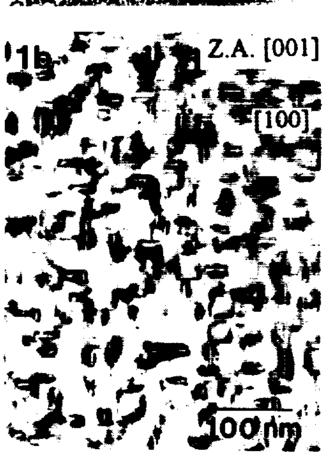


Fig. 1 (a) General microstructure of the NiAl-3Ti-0.5Hf single-crystal alloy in the as-heat treated condition. A higher magnification view of region F and its SADP are shown in (b,c), respectively.
Fig. 2 Preferential precipitation of large Ni_2AlTi plates and equiaxed Ni_2AlHf phase along a <110> direction in a $<001>_{NiAl}$ zone-axis.