Alloys and Intermetallics

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Structural Defects in Advanced Alloys and Intermetallics

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Advanced alloys and intermetallics combine high mechanical strength with excellent resistance to corrosion and oxidation in harsh environments. In the present study we investigate microstructural background of their mechanical strength. A focus is on directionally solidified NiAl-(Cr)-Mo eutectics, CoCrFeMnNi high entropy alloys and more conventional Ni-based superalloys single crystals. We first introduce a novel STEM HAADF technique which provides an insight into 3D arrangements of dislocation structures [1]. In order to demonstrate a potential of the technique, we first review some basic elements of classical stereo TEM. We then show how the method can be extended by working in the scanning transmission electron microscope (STEM) mode of a modern analytical based 200 kV TEM equipped with a field emission gun (FEG TEM) and a high angle annular dark field (HAADF) detector. Two STEM micrographs of a stereo pair combine into one anaglyph. When viewed with special coloured glasses the anaglyph provides a direct and realistic 3D impression of the microstructure, see Figure 1. The technique is then applied in order to resolve spatial dislocation arrangements in the series of structural materials. In particular, dislocation processes at the NiAl-Mo and NiAl-Cr interfaces in the directionally solidified NiAl-(Cr)-Mo eutectics are investigated in detail. Directionally solidified NiAl-(Cr)-Mo composites exhibit microstructures of major (NiAl matrix) and minor (Mo or Cr fibre) eutectic phases. Recent advances in processing have resulted in NiAl-(Cr)-Mo microstructures of unprecedented quality in terms of alloy purity and microstructural regularity. The NiAl-(Cr)-Mo microstructure was investigated by STEM before and after creep. The results of the analysis clearly show that the formidable high-temperature strength of NiAl-(Cr)-Mo in situ composites is associated with the presence of fine Mo or Cr fibres. Since fibres are essentially dislocation-free in the as-solidified microstructure, they can support the high stresses associated with dense dislocations structures. We show that later in creep life, dislocations can be transmitted from the NiAl intermetallic matrix through the interfaces into the reinforcing eutectic phase. These processes invert the strain accumulation kinetics at high temperatures and thus cause weakening of the material [2]. Similarly, a combination of dislocation slip and deformation twinning in new class of solid solution high entropy alloys results in unique deformation behaviour. An equiatomic CoCrFeMnNi high-entropy alloy, which crystallizes in the face-centered cubic (FCC) crystal structure, was produced by arc melting and drop casting. The drop-cast ingots were homogenized, cold rolled, and recrystallized to obtain single-phase microstructures with three different grain sizes in the range 4~160 µm. Quasi-static tensile tests at an engineering strain rate of 10^{-3} s^{-1} were then performed at temperatures between 77 and 1073 K. Yield strength, ultimate tensile strength and elongation to fracture all increased with decreasing temperature. During the initial stages of plasticity (up to ~2% strain), deformation occurs by planar dislocation glide on the normal FCC slip system, {111}<110>, at all temperatures and grain sizes investigated. Undissociated 1/2<110> dislocations were observed, as were numerous stacking faults, which imply the dissociation of several of these dislocations into 1/6<112> Shockley partials. At later stages (~20% strain), nanoscale deformation twins were observed after interrupted tests at 77 K, but not in specimens tested at room temperature where plasticity occurred exclusively by the afore-mentioned dislocations. The STEM HAADF analysis suggests that excellent ductility observed at 77K is due to a unique combination of dislocation and twinning deformation modes [3].

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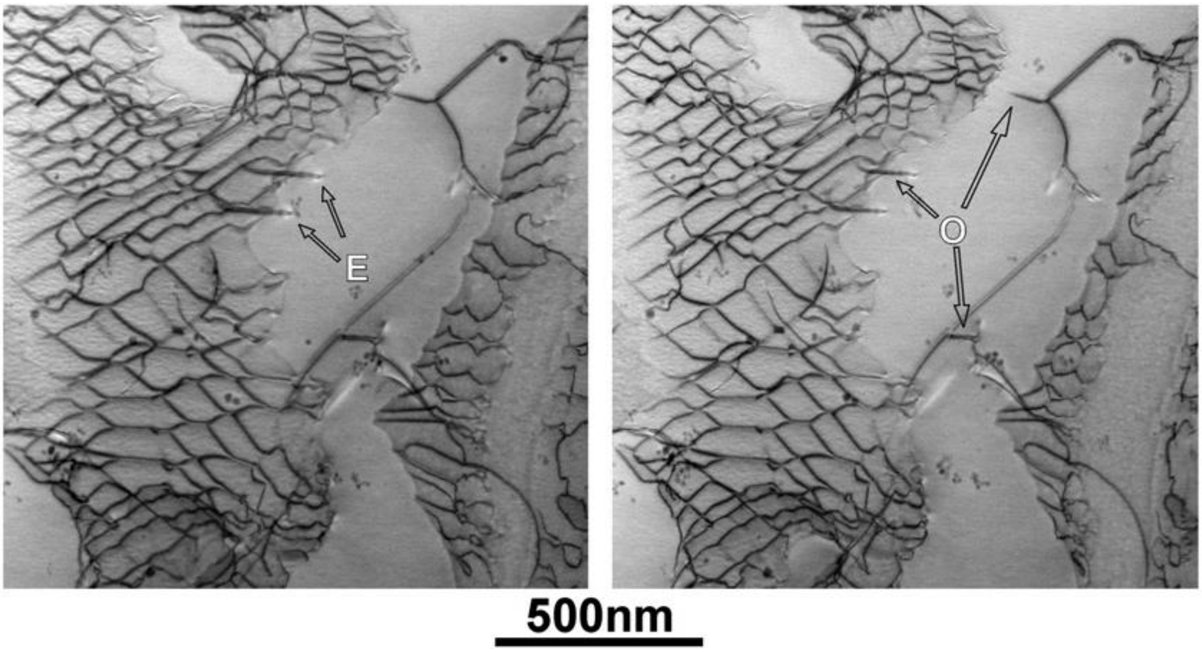

Figure 1. Stereo transmission electron microscopy of a crept Ni-base single crystal superalloy (LEK94, 160MPa, 1020°C, 2%). Corresponding stereomicrographs obtained using STEM HAADF technique (inverted contrast).