The Ductility of Ni₃Al and the Accommodation of Slip at Grain Boundaries

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Polycrystals of Ni₃Al are brittle, even though slip can occur on five independent systems and single crystals are ductile. The brittleness appears to be related to the difficulty of accommodating slip at grain boundaries. The observations supporting this view are the following:

- (i) Impurities have not been detected on intergranular facets, suggesting that the brittleness is an intrinsic characteristic (1).
- (ii) Yielding precedes fracture (2).
- (iii) Dislocations pileup at grain boundaries before slip is transmitted (3,4), leading to localized stress concentrations.
- (iv) Boron segregates to grain boundaries (5). The addition of a small amount of this element (0.35 at.%) reduces by 40% the effectiveness with which grain boundaries impede slip (3), Figure 1. The addition also reduces the contribution of grain boundaries to the hardness of Ni₃Al (6). Correspondingly, boron raises the room temperature ductility (6) of stoichiometric material from almost zero to >10%, Figure 2. When added to Ni-rich material, the boron raises the ductility to over 50% (5).
- (v) The addition of boron raises the critical grain size at which the transition from brittle to ductile behavior occurs upon grain refinement (6). Figure 2.
- (vi) Theoretical arguments (7) suggest that in segregating to grain

boundaries boron attracts nickel. Measurements (8) using a VG high-brightness STEM support this view, Table. The excess nickel lowers the degree of long-range atomic order and thereby eases the movement of grain boundary dislocations by lowering the energy barrier to their movement. Such movement accommodates slip and is required to avoid crack nucleation at the head of a dislocation pile-up.

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Figure 1. The yield strength at room temperature versus (grain size)^{-0.8} of stoichiometric Ni₃Al with (0.35 at.%) and without boron. Note that the addition of boron raises the intercept owing to solid solution strengthening of the lattice, but lowers the slope owing to a reduction in the effectiveness with which grain boundaries impede slip. The grain size dependence can be quantitatively explained in terms of a work hardening model of yielding. (Taken from ref. 3.).

Figure 2. The elongation at room temperature versus grain size of stoichiometric Ni₃Al with (0.35 at.%, open symbols) and without (closed symbols) boron. Although scattered, the data indicate that the ductility of the alloy containing boron increases with decreasing grain size. (Taken from ref. 6.).

VG STEM TABLES

Stoichiometric Ni₃Al

No. of counts	Ni	Al	Calculated atomic%		Thickness (nm)	Absorption correction for Al
			Ni	Al		
72,801	10,510		75.7	24.3	31	1.12
99,275	13,365		75.7	24.3	51	1.19
176,127	19,428		75	25	126	1.51
91,033	11,734		75.2	24.8	72	1.28
63,792	8,494		75.9	24.1	50	1.19

Ni₃Al + Boron (0.35 at.%)

45,604	4,547	78.7	21.3	90	1.36
35,444	3,348	79.8	20.2	83	1.34
15,988	692	84.5	15.5	235	2.1
17,483	539	87.4	12.6	260	2.3
40,101	3,892	78	22	111	1.46
34,721	3,179	79	21	111	1.46