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THE STRENGTH AND DUCTILITY OF POLYCRYSTALLINE NiAl IN TENSION

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The purpose of this paper is to review the results of an experimental study under way at Dartmouth on the tensile strength and ductility of the B2 aluminide, NiAl. Specifically, ductility at low temperatures is being sought through two routes, grain refinement and microalloying. Experiments at temperatures from 20°C to 400°C at two strain rates (1×10^{-4} S^{-1} and 5×10^{-6} S^{-1}) have established that:

i) at room temperature, binary and microalloyed (< 1000 ppm La, Y, Mo, Ti) NiAl shows negligible ductility, independent of grain size over the range 5 to 140 μm;

ii) at 295°C the tensile elongation of binary 51 Ni/49 Al increases from < 1% to about 5% upon decreasing the grain size to below ≈ 10 μm;

iii) similarly, at 400°C the ductility increases from about 2% to > 15% upon decreasing the grain size to below 15 μm;

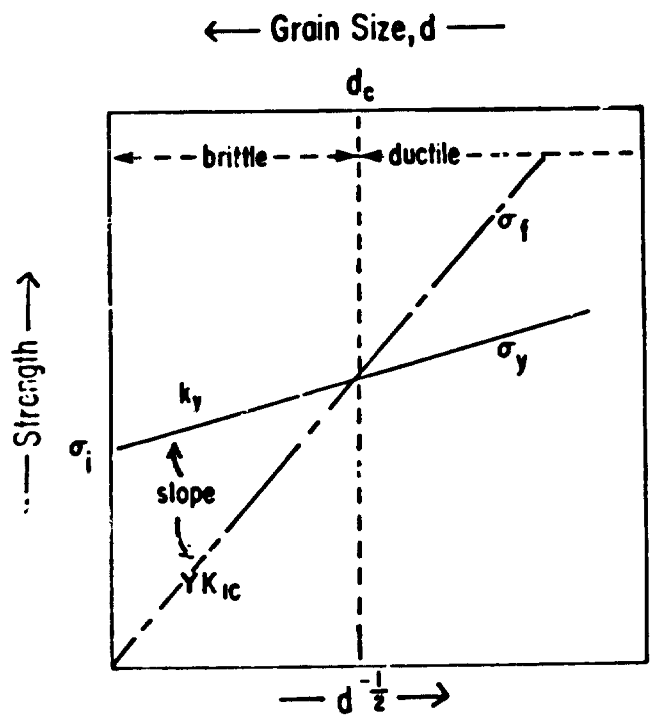
iv) the ductility of fine-grained (7 μm) binary aggregates deformed at 295°C increases from ≈ 5% to 12% upon decreasing the strain rate from 10^{-4} S^{-1} to 5×10^{-6} S^{-1};

v) partial recrystallization (10 to 20%) of warm-extruded binary and microalloyed material imparts 1 to 2% ductility at room temperature where fully recrystallized material is brittle (point (i));

vi) the yield strength obeys a Hall-Petch relationship; and

vii) when ductility is not observed, fracture coincides with yielding.

The mechanisms underlying the flow and fracture of NiAl are discussed in terms of the nucleation and growth of microcracks. The concept of a critical grain size, presented elsewhere (E.M. Schulson, Res. Mech. Lett. 1 (1981) 111), is considered in the light of the above results.



$$d_c = \left(\frac{YK_{IC} - k_y}{\sigma_i} \right)^2$$

TEST MATERIALS

Alloy	Composition (wt.%)						
	Ni	Al	Mo	Ti	Y	La	B
1*	69.3	30.7					
2	69.2	30.7	0.075				
3	69.3	30.7				< 0.03	
4	69.3	30.7			0.02		
5	69.2	30.7	0.068	0.056			
6	69.2	30.7					0.10

*The base, Alloy-1, is 51 at.% Ni/ 49 at.% Al

TRACE ELEMENTS (ppm) IN ALLOY-1

Element	Concentration (ppm) in Alloy-1
C	20
O	< 70
N	3
S	< 10
Zr	125
Fe	200
Si	100
Mg	10

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MATERIALS PROCESSING

1) Hot-extrude* ingots to 19 mm rod at ≈1000°C through area reduction ratio of 7:1.

2) Re-extrude* to 6 mm rod at ≈ 550°C through area reduction ratio of 7:1.

3) Recrystallize⁺ at temperatures between 700°C and 800°C to produce either partially recrystallized or fully recrystallized material of grain size from 5 μm to 140 μm.

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*See attached table of extrusion constants for details.

⁺See attached paper on recrystallization and grain growth.

Extrusion Conditions and Extrusion Constants for Binary and for Alloyed NiAl

Extrusion No.	Ingot & Alloy	Ext. Temp. (°C)	Avg. Ext. Speed (in./min)	Ext. Ratio, R	% of NiAl in Billet	F_B (a) (tons)	K_B (b) (ksi)	F_F (c) or (tons)	F_{SS} (d)	K_F or K_{SS} (ksi)
-- Hot Extrusions of Ingots to 0.75 in. rod --										
80-36	Binary	1090	-	8.0	100	211	58		172	47
81-25	Binary	997	16	7.9	82	201	55	261		72
81-32	Binary	1000	16	7.0	82	191	56	264		77
81-33	+B	992	stalled	7.0	82	300	88	-press stalled at 347 tons -		
81-34	+Mo	1008	26	6.9	82	218	64	234		69
81-40	+Mo+Ti	1000	26	6.9	82	195	57	218		64
81-46	+La	1005	23	6.9	82	191	56	234		69
81-47	+Y	1002	24	6.9	82	195	57	224		66
81-54	Binary	955	31	6.9	83	231	68		191	56
81-55	+B	1070	15	6.9	82	284	83	327		96
-- Warm Re-extrusions --- 0.75 in. rod to 0.25 in. rod --										
80-54	Binary (80-36)	499	stalled	7.9	11	press stalled after breakthrough				
81-52	Binary (81-32)	546	28	7.1	13	330	96		300	87
81-68	Binary (81-32)	474	37	4.5	13	333	126		300	113
81-69	Binary (81-32)	565	37	7.1	13	327	95		281	82
81-70	Binary (81-32)	503	36	7.1	13	330	96		284	82

(a) F_B = breakthrough force

(b) K_B = extrusion constant at breakthrough

$= \frac{F_B/A}{\ln R}$ where A = cross-sectional area of billet

(c) F_F = final force

(c) F_{SS} = steady state force

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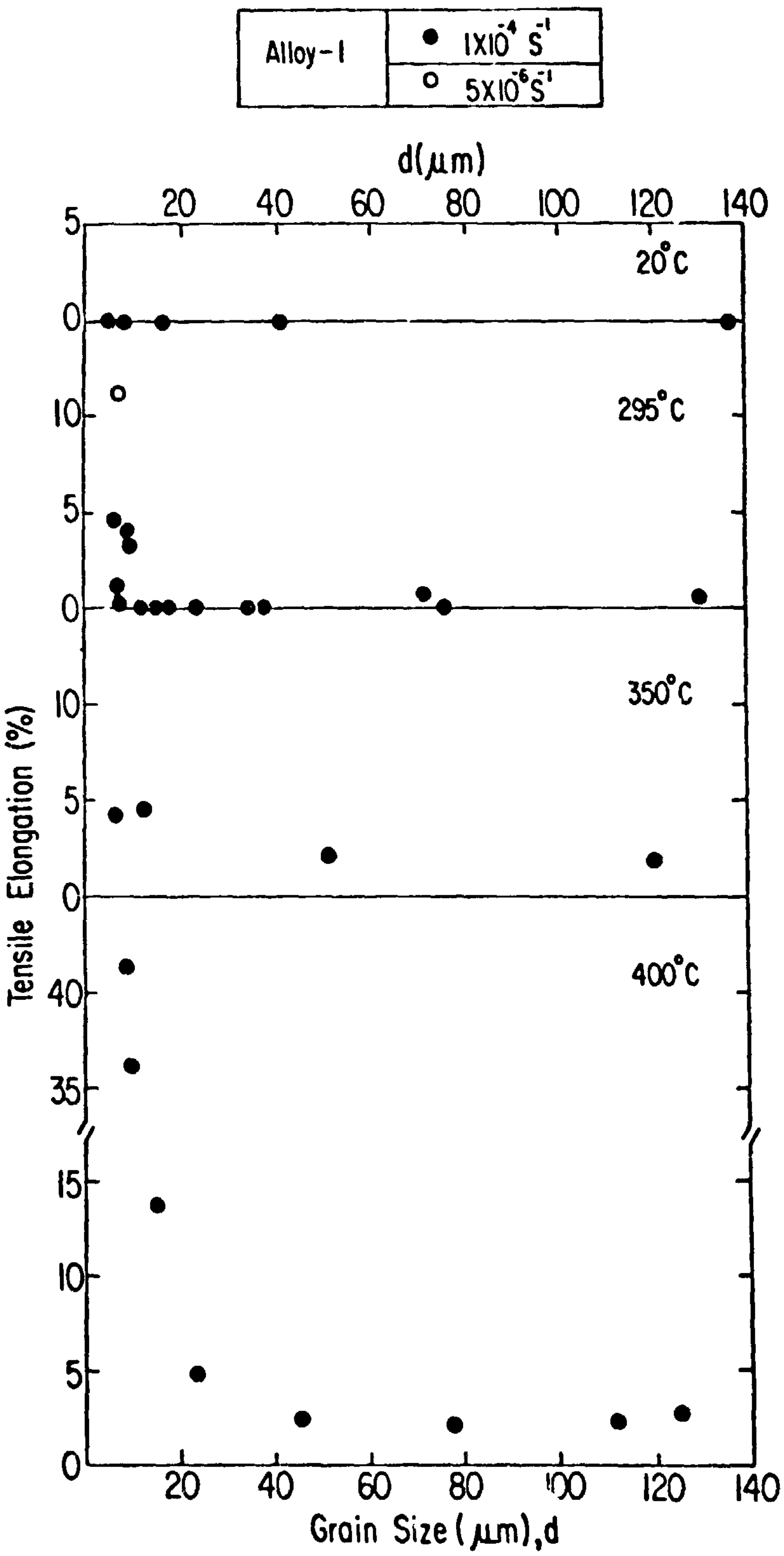

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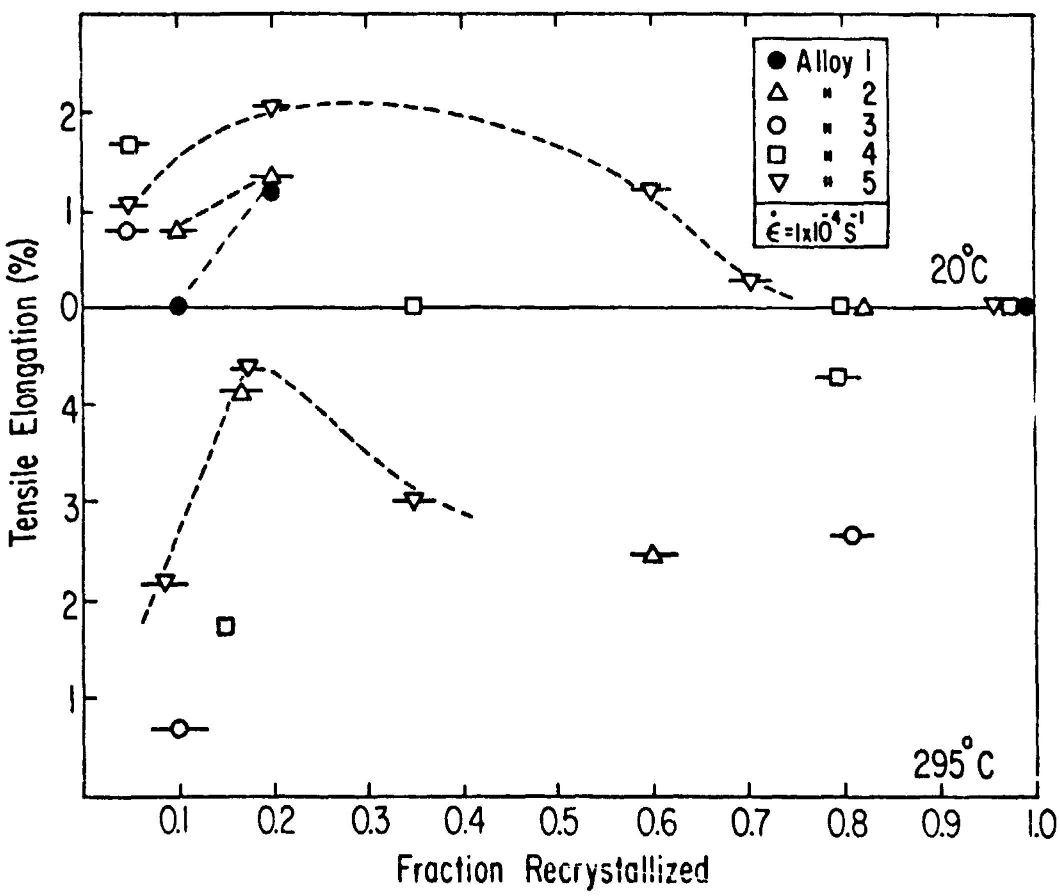
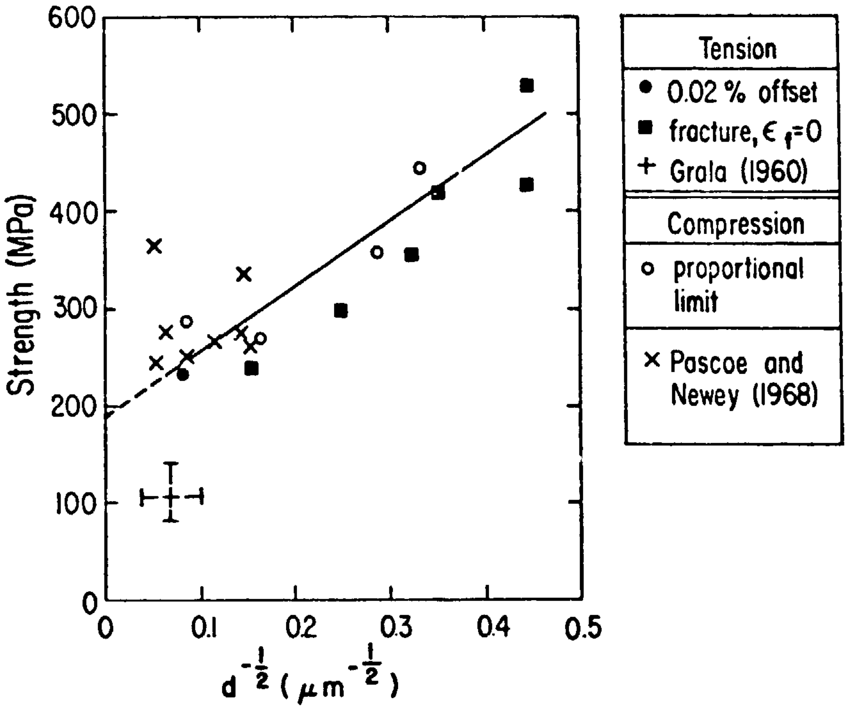
DUCTILITY OF PARTIALLY RECRYSTALLIZED NiAl

Material	Strain Rate (S^{-1})	Temp. (°C)	Fractional Recrystallization	Elongation (%)
Alloy-1	1×10^{-4}	20	0.2	1.2
		295	0.1	7.4
		400	0.1	64.1

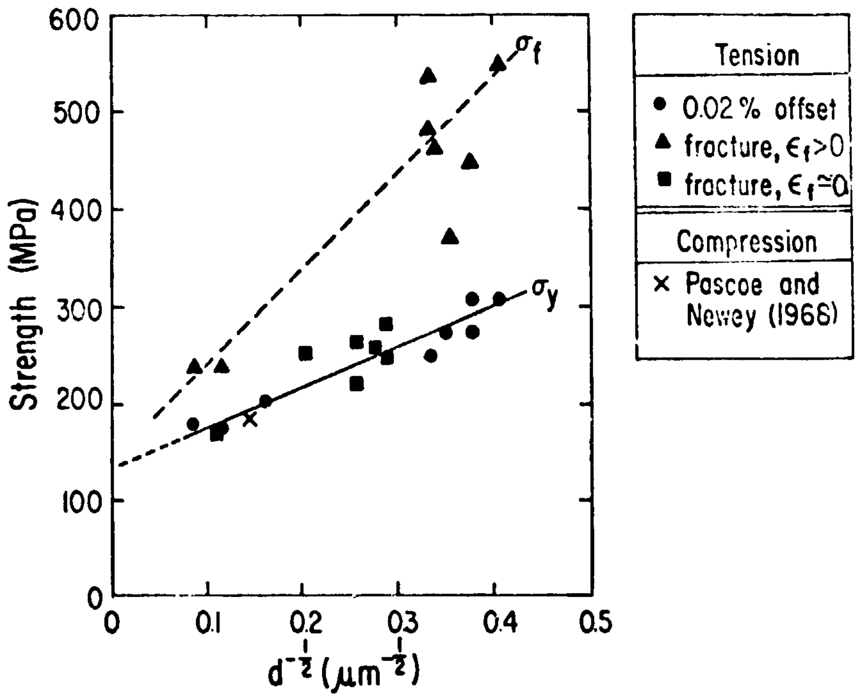


Alloy −I; 20° C



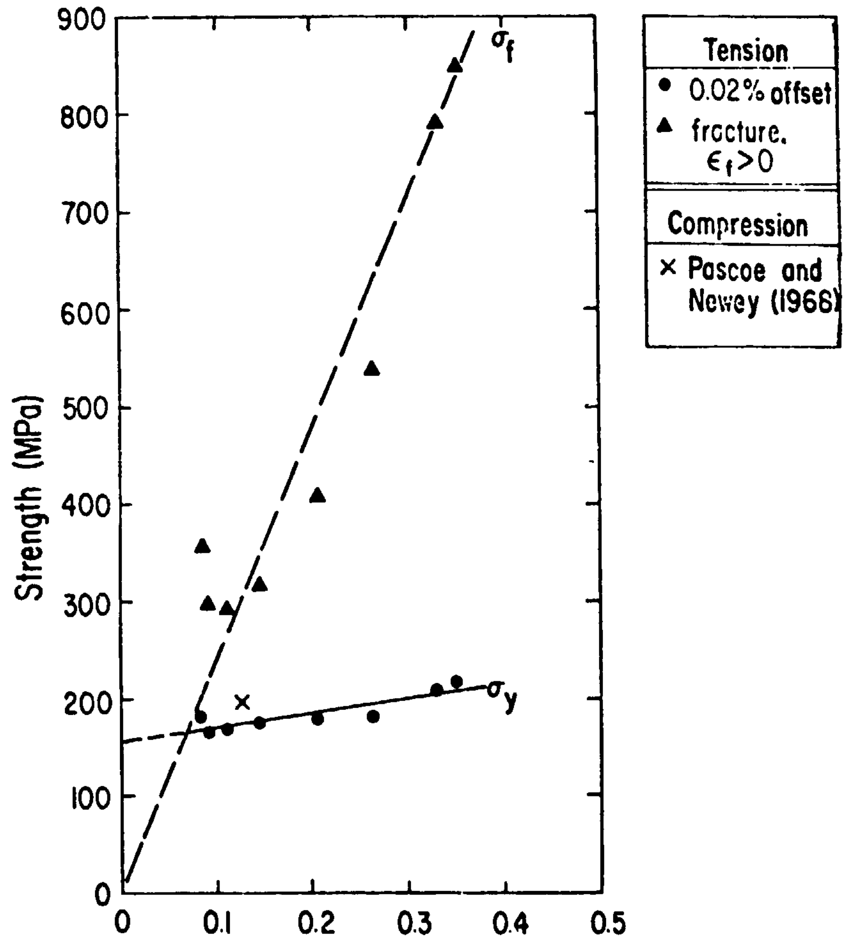
σy (MPa) = 189 + 0.67 d(m)$^{-1/2}$

Alloy-I; 295° C



σy (MPa) = 133 + 0.41 d(m)$^{-\frac{1}{2}}$

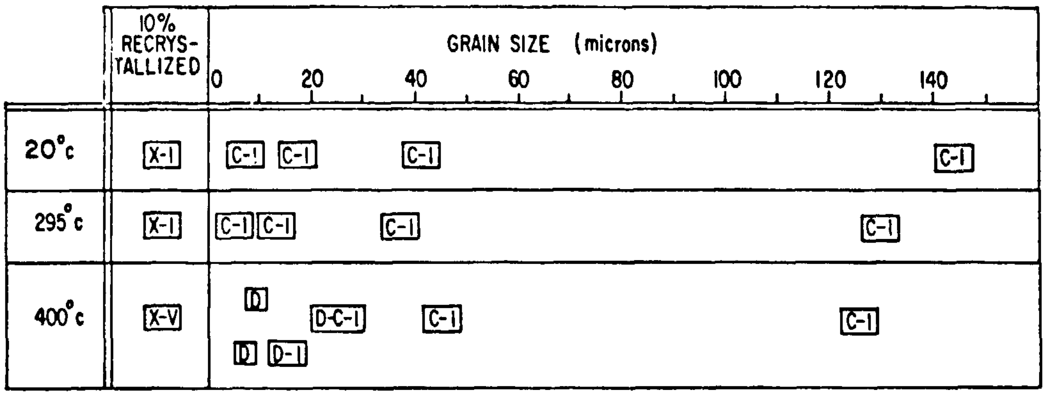
Alloy -I; 400° C



$d^{-\frac{1}{2}}$ ($\mu m^{-\frac{1}{2}}$)

$\sigma y \text{ (MPa)} = 152 + 0.16\ d(m)^{-\frac{1}{2}}$

FRACTURE MODES: Alloy-I



I = Intergranular
C = Cleavage
D = Ductile, torn appearance
V = Microvoids
X = Unrecrystallized grains prevent characterization