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STRENGTH OF ALUMINIUM NITRIDE WHISKERS

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ANALYSIS of the strength of materials, from an atomistic point of view, predicts that the ratio, α, of fracture stress (σ) to initial strain (ε) in atomic bonds will be of the order of 10 per cent E (E = Young's modulus). A value of α of this magnitude should be obtainable for perfect crystals. Whereas in practice yielding occurs in high-strength structural materials when α is about 1 per cent E, it has been known for a long time that whiskers or fibres of almost all materials, with diameters of $\sim 10^{-4}$ cm, and large length/diameter ratios show values of α near to the ideal value. Non-metallic whiskers having mixed ionic/covalent bonding with low specific densities and high melting-points have been examined as strengthening media for fibre-reinforced materials[1]. Analysis of fibre-reinforced systems have recently been made by Cottrell[2] and Kelly[3].

Aluminium nitride is a refractory material which may be considered suitable as a fibre-reinforcing material. Whiskers of this material were prepared by heating aluminium nitride powder (contained in an alumina crucible), at temperatures up to 1,820° C in an alumina tube in a flowing atmosphere of high-purity nitrogen diluted with high-purity argon. Chemical and X-ray analysis of the whisker product confirmed that the whiskers were aluminium nitride. The whiskers formed on cooler sections of the container. It is suggested that the whiskers grow by a process of dissociation of aluminium nitride powder at the operating temperature with subsequent growth of whiskers, from a vapour phase, at a cooler substrate. Straight whiskers, about 18–20 mm long, were formed after 15 h at temperature, giving an average growth rate of about 1·5 mm/h. Some of the whiskers with good morphological symmetry had 'kinks' and 'branches' (Fig. 1) and it was also observed that a whisker changed its axial growth direction by about 2° (minimum) to 20° (maximum) over its length. Platelets formed at slightly higher temperatures showed surface striations (Fig. 2); under oblique illumination these striations appeared to be growth steps and not slip planes perpendicular to the major growth axis. The results of bend and tensile strength determinations on whiskers are given in Tables 1 and 2.

Bend-strength tests. The whiskers were subjected to bending on a Reichart microscope stage. Fig. 3 shows a typical bend in a whisker before fracture. All these tests were conducted with the whisker lying in a film of oil.

For perfectly elastic bending, the tensile stress in the outer surface of a fibre can be expressed as:

$$\sigma = \frac{Er}{p}$$

where σ = tensile stress in outer fibre; E = Young's modulus; r = radius of fibre; p = radius of curvature. It was observed that fracture occurred most frequently in whiskers containing common types of structural imperfections, that is, low-angle kinks, whiskers with twists of about 10° along their length and whiskers with surface growth steps.

The majority of whiskers were extremely flexible and it was sometimes difficult to obtain a sufficiently small

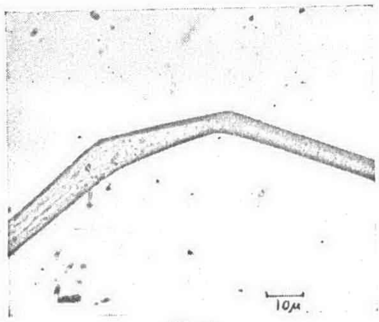

Fig. 1

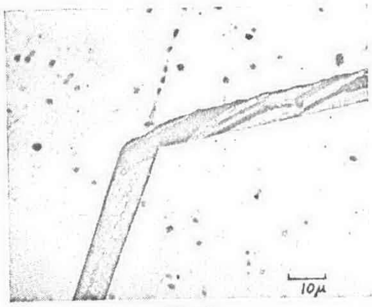

Fig. 2

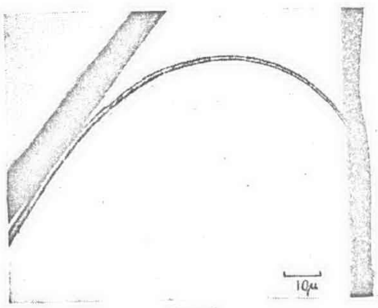

Fig. 3

Table 1. BEND STRENGTH OF ALUMINIUM NITRIDE WHISKERS ($E = 50 \times 10^6$ lb./in.^{2})

No.	Length ($\mu \times 10^3$)	Cross-section (μ)	p (μ)	$\sigma = \frac{Er}{p}$ (lb./in.^{2})	$\frac{\sigma}{E}$ (%)
1	7·3	2·5 × 4·0	60	$1·04 \times 10^6$	2·08
2	4·2	2·5 × 3·0	58	$1·08 \times 10^6$	2·16
3	5·0	2·8 × 3·5	72	$0·97 \times 10^6$	1·93
4	7·5	7·2 (hex)	1,820	$9·9 \times 10^4$	0·02
5	5·2	6·5 (hex)	1,720	$9·5 \times 10^4$	0·19
6	5·0	5·5 (hex)	1,900	$7·25 \times 10^4$	0·02
7	8·2	3·0 × 8·0	75	$1·0 \times 10^6$	2·00
8	8·3	$8·0 \times 10^2 \times 2·5 \times 10^2$ (platelet)	10^4	$1·25 \times 10^4$	—
9	4·7	3·5 × 2·5	78	$0·8 \times 10^6$	1·60
10	4·2	3·7 × 2·8	82	$0·88 \times 10^6$	1·75
11	5·0	4·0 × 2·2	2,500	$2·2 \times 10^4$	—
12	5·2	8·0 × 2·5	10^4	$6·7 \times 10^3$	—

All specimens except No. 6 were immersed in oil during testing. All specimens except Nos. 11 and 12 were bent about an axis parallel to the longest side of the cross-section; Nos. 11 and 12 were bent about the shorter cross-sectional axis. Specimens 4, 5 and 6 were produced in the image furnace[4]; for these specimens with a hexagonal cross-section the mean diameter is given.

Table 2. TENSILE MEASUREMENTS (GAUGE LENGTH 1·0 cm)

No.	Whisker section (μ)	Load at fracture (g)	Fracture stress (σ) (per lb./in.^{2})
1	10 × 38	272	$1·02 \times 10^6$
2	17 × 22	188	$0·72 \times 10^6$
3	9 × 42	260	$0·98 \times 10^6$
4	11 × 37	268	$0·94 \times 10^6$
5	10 × 39	272	$0·99 \times 10^6$
6	8 × 45	268	$1·06 \times 10^6$
7	26·3 mean diam. (hex)	52	$0·14 \times 10^6$
8	28·6 mean diam. (hex)	53	$0·13 \times 10^6$