LETTERS TO THE EDITOR

PHYSICS

High Elastic Modulus Carbon Fibre

PRESENT-DAY interest in fibre reinforced composite materials has been centred on the difficulty of preparing suitable filamentary materials in large quantities. The attractive physical properties of whisker crystals have not, as yet, been exploited, because of the difficulties of bulk production of uniform whiskers.

Of all filamentary materials, their physical properties give graphite whiskers greatest potential for composite development. Small quantities have been prepared and they are reported¹ to possess the highest tensile strengths (3×10^6 lb./in.²) and Young's moduli (about 130×10^6 lb./in.²) yet recorded for any material. In addition to this, the specific gravity is low (2.27) and the high strength and high modulus can be expected to be maintained to high temperatures. But, again, these whiskers are not amenable to bulk production by present techniques.

Carbon fibres are available commercially in relatively large quantities, but their tensile strengths and Young's moduli are too low (about 10^5 lb./in.² and $5-10 \times 10^6$ lb./in.², respectively) for them to be of any significant use as structural elements in composite materials.

We have prepared carbon fibres of high elastic modulus in continuous lengths and in relatively large quantities, by precisely controlled heating of commercially available textile fibres to 3,000°C in both reactive and inert atmospheres. Average values of Young's moduli greater than 60×10^6 lb./in.² with peak values more than 100×10^6

Fig. 2. Cross-section of carbon fibre reinforced polyimide resin ($\times 400$)

lb./in.² have been attained. Average tensile strength values of 250,000 lb./in.² are typical. Fig. 1 shows typical modulus and strength distributions. The specific gravity of such fibres is usually in the range 1.8–2.0. The tensile strength and modulus values reported for graphite whiskers indicate that these carbon fibre values are potentially capable of great improvement, but the present values are sufficiently high to make these fibres outstanding.

Table 1. COMPARISON OF THE MECHANICAL PROPERTIES OF A NUMBER OF ALLOYS WITH THOSE OF A CARBON FIBRE EPOXY RESIN COMPOSITE

Material	Density (lb./in. ³)	Tensile strength (lb./in. ²)	Young's modulus (lb./in. ²)	Specific strength (in. ⁻¹)	Specific modulus (in. ⁻¹)
Aluminium alloy—A/FLS	0.100	45,000	10.5×10^6	450×10^3	105×10^6
Titanium alloy T/AM	0.164	65,000	17×10^6	400×10^3	105×10^6
Fibre glass epoxy XP219	0.076	155,000	7×10^6	$2,000 \times 10^3$	92×10^6
Carbon fibre epoxy	0.061	90,000	40×10^6	$1,500 \times 10^3$	660×10^6

Composites produced from this material include carbon fibre reinforced epoxy resin and carbon fibre reinforced polyimide resin. A comparison of the properties of the carbon fibre epoxy composite with those of other materials is shown in Table 1.

Fig. 2 shows a typical cross-section of carbon fibre reinforced polyimide resin.

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¹ Bacon, R., *J. App. Phys.*, **31**, 283 (1960).

Effects of Long-chain Molecule Additives in Water on Vortex Streets

THE spectacular reductions of turbulent friction which can occur as a result of dissolving certain long-chain molecule substances in water¹ have still not been adequately explained. An explanation might be sought in terms of a continuum theory relating the stresses in the fluid to its motion. Various logically possible sets of such constitutive equations have been proposed, and both the second-order fluid of Coleman and Markovitz² and the anisotropic liquid of Ericksen³ seem attractive as possible models of dilute polymer solutions. It is desirable, therefore, to try to devise simple experiments which will help to decide which model fits the real fluids best and determine the disposable constants in the theoretical model.

Fig. 1