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FIBROUS COMPOSITES and CARBON FIBRES

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Materials

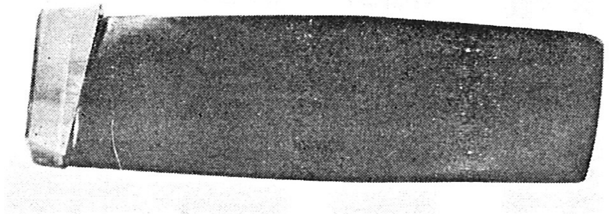
EVERYTHING tangible consists of materials—and far too many people assume that for design purposes the properties of a material will be isotropic, or uniform in all directions throughout its bulk. In fact this is comparatively rarely so, and most materials are anisotropic (or non-uniform) to some extent. A rolled steel joist, for example, is designed into use as part of a building or machine according to the details of intended loading, which depend upon its shape, and also upon the characteristics of the material " within " its shape. Having been designed, a joist (or any component) is then only of maximum use in that particular situation—it may be useless under some other loading. For example, an I-section joist rotated 90° about its longitudinal axis would be of very little use for supporting the cantilever or centre hung loads for which it was intended. Many plastics, too, illustrate the relationship of use both to anisotropic properties and to design. Heat a blown thermoplastic for example and the lines of internal material stress become apparent as the object shrinks and warps—this sort of " structure " is often regarded as a nuisance, though the best type of design not only takes such factors into account, but uses them. Vacuum snap-back moulding makes use of " memory ", often troublesome, in other circumstances ; and forging of thermoplastics, and spinning, would hardly be possible if all plastics were truly isotropic.

A Natural Fibrous Composite

Timber is a natural material that demonstrates very well the usefulness of anisotropy and also the way it can be manifested in a fibrous composite. Wood can be regarded as a composite material of fibres (the " grain ") within a matrix (the " pulp ")—and the mechanism of breakage differs from one type of tree to another. Hard wood almost always fails in tension, because although it has adequate lignin to resist compression it is (relatively) short of cellulose fibre to withstand tension. Consequently, a hard wood tree such as mahogany subjected to bending force perhaps by the wind " learns " to grow cellulose fibres up the side of the tree that is being stretched—thereby subsequently making it very difficult for the timber man, whose plane tends to leave a fluffy cotton-like surface on wood from the windward side of the tree. Conversely soft woods, notable for their cellulose fibre content, usually fail in compression. Pine and similar trees when bent by the wind, concentrate lignin up the side of the cross section away from the wind where the compression load is felt. Trees are " lucky " because they can adjust the relative positions and concentrations of tension-resisting and compression-resisting materials as they grow, and as they discover what sorts of load are put upon them. Man-made materials, however, have their problems anticipated for them—by the designer: and particularly with plastics, metals and concrete, man has available to him a simple and versatile means of designing to almost any eventuality.

Composites Generally

There are, of course, all manner of composite materials in which different components are brought together, each contributing some technical or economic benefit. Dispersion-hardened metals (hardened by precipitated and distributed alloy particles), bread (a solid/gas composite), flexible glass (where an ion-exchanged skin under compression balances an inner core of glass in tension), earth,



Blade made of carbon fibre, Rolls Royce Ltd.

butter (an oil/water emulsion), and ordinary concrete, are just six examples of " non-fibrous " composites. They have widely differing properties which are deliberately achieved in different ways.

Fibrous composites are usually made to achieve greater strength, or stiffness, per unit volume or weight, than could otherwise be obtained. The matrix substance can provide the bulk and often non-specific properties of the material ; and the fibre content can act as reinforcement or pre-stressing, according to design possibilities and service needs. For straightforward applications, designing too is straightforward, but there are, of course, interesting practical problems which arise largely because such composites are used to improve upon existing materials, or for uses beyond them.

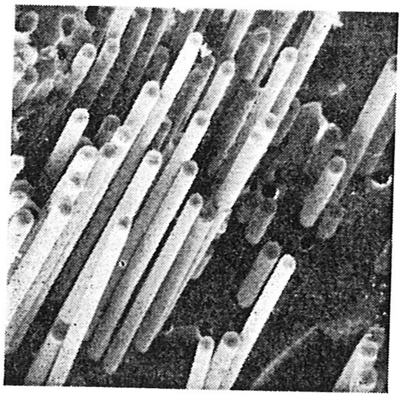
Asbestos/cement was a remarkable material when it first came out. Tensile strength imparted by asbestos fibres combined with the hardness given by the cement, enabled cheap sheet materials for walls and roofs to be lighter for the same strength than would otherwise have been possible with non-metallic materials. Asbestos has also been used as a reinforcement for thermosetting resins. Chemical plant made of such material requires both the resin and the fibre to have a sufficient degree of chemical resistance, combined with mechanical strength.

More modern is glass-reinforced-polyester. Well known examples of such composites are asbestos/cement and glass-reinforced plastics of the thermosetting type. Glass-reinforced-polyester is suitable for many sophisticated engineering applications. However, as with asbestos/cement, GRP has tended to incorporate the reinforcements in all directions, and in most cases without more than a token attempt to design the material at the same time as designing the components made from it. The specialist filament winders are exceptions, of course, and also Rolls Royce Ltd. who use glass fibre composite materials in the construction of the Rolls Royce RB 162 Lift Jet Engine. Cooler components, including the nose cone and intake faring, the compressor casing of the stator blades, and all but the first stage of compressor rotor blades are made out of glass fibre composite materials. Here the material is certainly designed, and to the same extent as is the shape of, for instance, the blades. By suitably disposing the fibres, their strength can be used exactly to the extent required by the design.

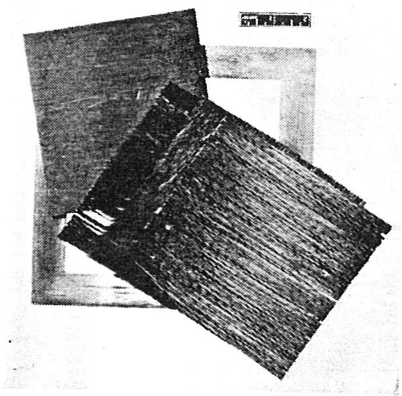
Naturally designers of advanced equipment like jet engines are continually on the look out for other stronger and more useful materials.

High Strength Filaments

Whiskers are perhaps the strongest form in which any material can be known. They may be made of carbon, silicon nitride, boron, and many other compounds, and



Fracture surface of a carbon fibre epoxy resin composite, Morganite Research & Development



Pre-preg sheets showing how they can be cross-plied, with frame mould and cured sheet of CFRP behind them, RAE, Farnborough

are generally formed by deposition from decomposing gases. They are a few microns thick and are (relatively) long single crystals ; and this is the secret of their strength. They do not contain cracks or other discontinuities that would be present in bulk material, because their crystalline structural perfection obviates this. In England much whisker work has been done at the Explosives Research and Development Establishment at Waltham Abbey in Essex. Silicon carbide whiskers may have an ultimate tensile strength of up to 3,000,000 psi and are stronger than any of the conventional materials. Used as stiffening in plastics for exotic applications, strength to weight ratios can be achieved that were previously unobtainable. However, whiskers suffer from the difficulty of being relatively short, so that exact alignment in several particular directions may present difficulties—although there are simple techniques for aligning them in one direction. In the United States a great deal of work has been done both on the production of boron filaments by deposition on to tungsten and other substrates, and on their subsequent incorporation into resin matrices. It has been announced that the famous F.111 may use boron-fibre-strengthened plastics in its tail plane construction in order to save weight in the airframe.

Carbon Fibres

Another approach has been to use already existing fibres such as textile yarns and fibres which can be carbonised into forms that may have greater strength than they originally possessed as textiles. The first electric lamps used carbon filaments made this way—and other starting materials, too, were tried, such as grasses and slivers of bamboo. The Americans have taken the technique much further and have been experimenting with carbon-containing textiles ; and they have made a whole range of carbon fibres for various purposes, such as for incorporating into boiler suits to make them electrically conductive and so reduce the risk of the wearer getting an electric shock ; for making electric furnace heating elements ; and for applications where the chemical inertness of the carbon fibre is necessary.

Carbon fibres for purposes such as these have so far not required very much in the way of special mechanical properties. However, starting from viscose rayon, American companies have produced carbon fibres with ultimate tensile strengths and Young's modulus figures of the same sort of order as can be obtained with steels. The Union Carbide product is known as 'Thornel.' Of course the fibres need to be incorporated into some matrix, and then the properties of the composite material become somewhat inferior.

The RAE Process

In England the Royal Aircraft Establishment at Farnborough has been using other starting materials such as polyacrylonitrile and has invented a process, also involving the techniques of carbonisation and heat treatment of textile fibres, but from which the product has greatly improved properties. The tensile strength of these fibres is substantially over 100 tons psi, and the Young's modulus is some 60 million psi. When the fibres are incorporated at about 50 per cent volume fraction into a matrix of quite ordinary epoxy resin, the u.t.s. and Young's modulus of the resulting composite are of the same order as for steels, but with a much lower specific gravity. Thus carbon-fibre-reinforced plastics can have specific strength and specific stiffness (strength or stiffness divided by specific gravity) values significantly greater than are possessed by any other usable engineering material. This means that a large field is opened up for applications where lightness and rigidity are important together. As the carbon fibres are long, deliberate composite anisotropy is easily achievable, and the fibres may be used by filament winding circumferentially or longitudinally. Of course, such fibres can be deliberately chopped up and introduced in short lengths into the resins if circumstances so require. The result is that strength for strength, size for size, and rigidity for rigidity, a carbon fibre composite machine part or structural component will weigh only about a quarter as much as its steel counterpart.

Industrial Developments

Three firms in England have been studying the RAE process for making carbon fibres—Courtaulds, Morganite Research & Development, and Rolls Royce—and, of course, many in the United States of America, are considering its implications as compared with those processes based upon rayon. There is, naturally, a great deal of development still to do, but the process exists; work has begun to put it on a production basis : and Morganite Research & Development, and Courtaulds, will both supply to order. Costs are necessarily high at the moment, although substantially less in the UK than in the USA (where also the RAE process is not yet used, and the carbon fibres have significantly less attractive properties). In times to come when production lessons have been learned, and the scale of operations is sufficiently large, it is possible that carbon fibres could be in the same broad price bracket as the best glass fibres on a use-for-use basis.

For some years, however, carbon fibres will still be expensive though less so than competing filaments, such as boron.

How RAE Fibres compare with Steel and Glass

	RAE Carbon Fibres			
	High modulus	*High breaking strain*	*High tensile steel S99*	*HTS glass fibres*
Specific gravity ...	2·00	1·74	7·87	2·54
Tensile strength, lb/in² ...	300 × 10³	430 × 10³	190 × 10³	380 × 10³
Specific tensile strength, lb/in²	150 × 10³	250 × 10³	24 × 10³	150 × 10³
Young's modulus, lb/in²	60 × 10⁶	33 × 10⁶	30 × 10⁶	12 × 10⁶
Specific Young's modulus, lb/in²	30 × 10⁶	19 × 10⁶	3·8 × 10⁶	4·7 × 10⁶

(By courtesy of the Ministry of Technology)