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Potential for modern composites. Part 2

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Industrial applications of fibre composites

The leading composite materials permit the design of modern aircraft and the implementation of other projects which could not easily be achieved with traditional materials. For example, in the case of the first type of the Space Shuttle craft, with a length of 37 , a wing span of 24 m, weight of 68 tons and payload of 30 tons, more than 2500 kg of composites were used for constructional applications alone (Fig. 14). In the second type about 5000 kg more composites will be used. The largest component made from C/EP composite is the doors of the freight area (Fig. 15), weighing about 1.5 tons, with the use of almost 1 ton of composites giving a weight saving of 0.5 tons as compared with a design using light alloys. An aperture 4.5 × 18.3 m is covered by four parts measuring about 4.5 × 4.5 m, formed by a sandwich mesh with a honeycomb core of Nomex (a low-ignitability polyamide from Du Pont), reinforced with several ribs. The construction of the reinforcements for the engines, which transmit about 226 tons, is from a combination of titanium with boron-epoxide composite instead of titanium alone. The orbital manoeuvring system is also made from C/EP composite (Figs. 16, 17).

Seventeen cylindrical pressure vessels 1 m in diameter, for an excess pressure of 35 MPa, are made from a Kevlar/epoxide composite with an internal envelope (Fig. 18). Likewise tubing (Fig. 19) is from Kevlar/epoxide composite, 25—30 cm in diameter, pressure up to 0.8 MPa. At present work is being done on the development of C composites with a polyimide matrix instead of an epoxide one; this will increase the heat resistance from the present 170°C to 300°C and thereby will greatly facilitate the required heat insulation.

In aviation one of the first and most extensive applications of composites has been propellers and rotors for helicopters. Up to now about 50 all-composite rotors have been developed, 15 of which are currently in production. Rotors for wind-powered turbine generators, and some parts of the turbines, have also been designed and produced using composites.

In aircraft construction composites were first used in 1969 for the horizontal rudder of the F-14A aircraft, using boron fibres in an epoxide matrix, and a weight saving of 19% was achieved compared with the original version. In the case of the A-7D aircraft the wings were constructed from a B/C/EP composite (the envelope) and C/EP (the ribs). At present the horizontal rudder of the BI aircraft (with an area of more than

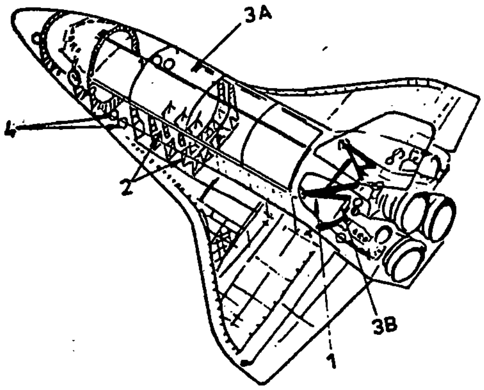


Fig. 14 Use of composites for a spacecraft:
1 — titanium reinforced with a boron/epoxy composite (construction of the engine reinforcements); 2 — a boron/aluminium composite (the tubular struts of the middle part of the fuselage); 3 — a carbon/epoxide composite; A — the doors of the freight area; b — the envelope of the orbital manoeuvring system; 4 — a Kevlar/epoxide composite (housings of the pressure vessels)

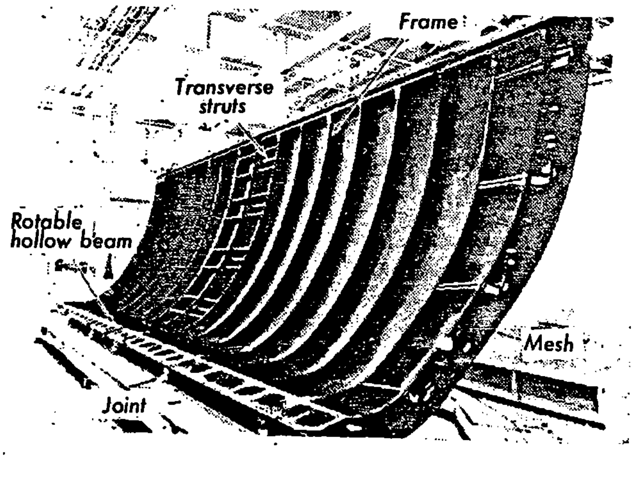


Fig. 15 Inside view of the doors of the freight area

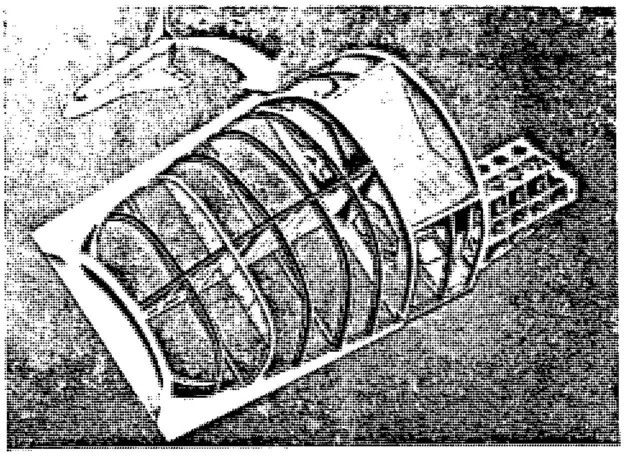


Fig. 16 Housing of the orbital manoeuvring system

10 m^2) is constructed predominantly from composites; a 15% weight saving and 17.5% cost saving were achieved. C/EP composites have been used for several elements of the British Tornado aircraft (Fig. 20); the engine housing of the Jaguar aircraft and the vertical rudder of the Viggen aircraft are made from composites. The vertical rudder of the F 16 aircraft is from a combination of metal and composite. Composites are extensively used in the British AV-8B Harrier vertical take-off aircraft with tilting jets, in which 26% of the weight of the construction is from C/EP composite. The weight of this aircraft is 5800 kg, and its load is 8100 kg for vertical take-off and 13500 kg for short take-off. For example, the entire wing (8.53 m long) is made from C/EP composite; it was formed from prepregs 0.3 m in width, with the thickness varying from 11.18 mm at the root of the wing to 2.45 mm at the tip, with eight transverse ribs. Among the primary constructional elements for aircraft one can mention a number of other examples combining Dural and composite elements, or with elements produced solely from C/EP or B/EP composites or from hybrid composites. The main problem is the need for production methods which give a fault-free product, with no pores, interlaminar defects etc. Consequently, simultaneously with the development of new composite systems and technologies, test methods are being developed, e.g. acoustic emission, microwave defectoscopy (46 Hz), scanning electron microscopy, X-ray radiography, ultrasonic techniques, opto-electronics etc.

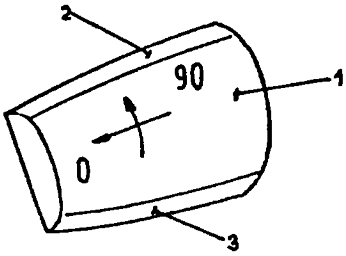


Fig. 17 Envelope of the housing of the orbital manoeuvring system, from a graphite/epoxide composite

Plane	Orientation of the layers of the envelope
1	±45 (fabric), 0/90 (fabric)
2	0/90 (fabric), ±45 (fabric), 0/90 (fabric)
3	0.0, 0/90 (fabric), ±45 (fabric), 0/90 (fabric), 0.0

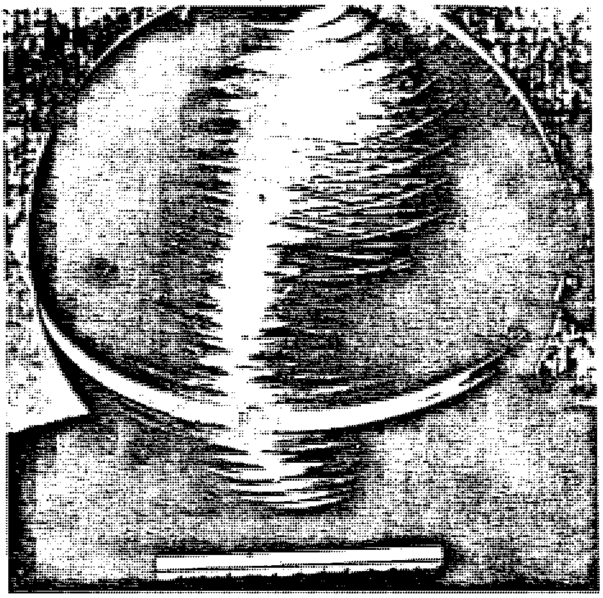


Fig. 18 Typical pressure vessel

Hybrid composites were first used for constructional parts in the Boeing 767 aircraft (Kevlar/C/EP, glass/C/Kevlar/EP). They are used, for example, for the flow housings of the wing attachment and for a number of items of equipment, where a conventional Dural construction is covered by a sandwich envelope from a hybrid composite with a core of Nomex

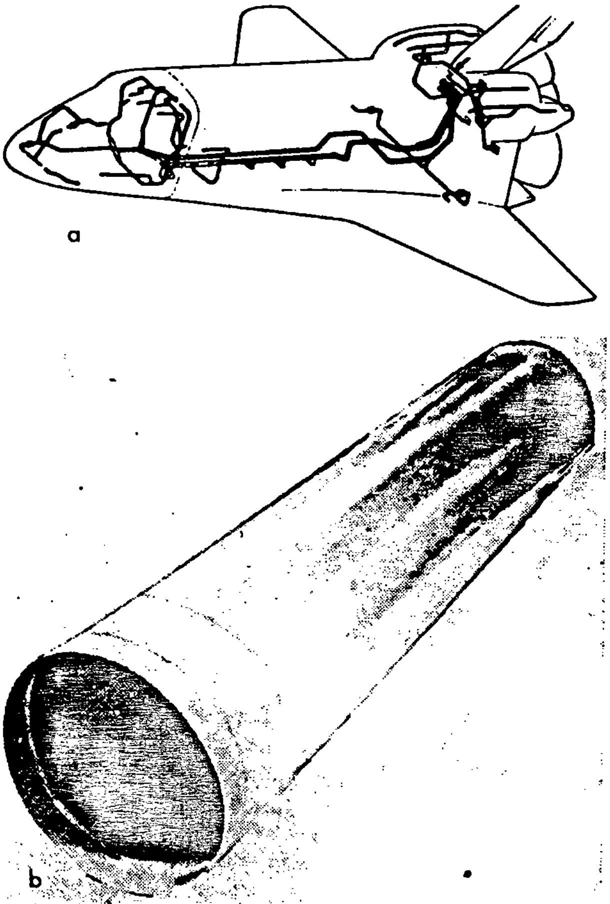


Fig. 19 Tubing from a Kevlar/epoxide composite

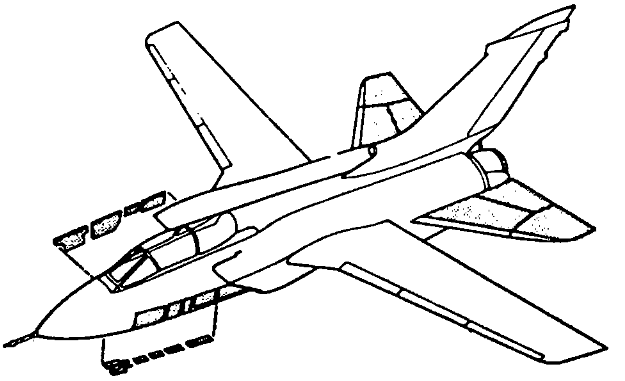


Fig. 20 The grey areas denote the use of composites with carbon fibres in the Tornado aircreaft (GB)

honeycomb, and for the doors of the control system (about 3.0 × 1.2 m) and for the main doors to the freight area. At present work is being done on the construction of main load-bearing elements on the same sandwich basis (Fig. 21). Another example is the F-28 aircraft, in which the undercarriage doors, brake flaps and wing flaps are from the hybrid C/Kevlar/EP.

The first all-composite aircraft was the Lear 2000, of 1981, for 6 passengers and 2 crew. The fuel-consumption is 0.28 litre/km, the speed 563 km/h at a height of 12.5 km, the wingspan 12 m, the wing area 15.1 m^2, the weight 1656 kg, the load 3255 kg, and the price 1,600,000 dollars (1981). Another example from the same year is the AS-W 22 all-composite glider, with a wing contour of 37 and a drag ratio of 57 (Fig. 22).

Further details about the construction of aircraft with the use of composites can be found in a series of articles by M. Paloda 'Composites in aircraft construction' in the second half of the current volume of the journal 'Letectvi a kosmonautika' ('Aviation and space technology').

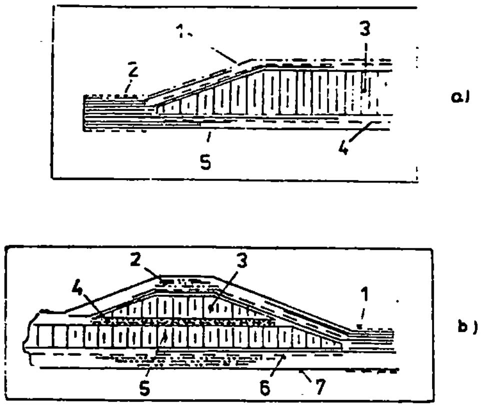


Fig. 21 Examples of arrangement of elements of a hybrid composite:
a — arrangement of the hybrid panel; b — formation of an integrated load-bearing element
(a): 1 — Kevlar fabric (120); 2 — fabric from glass fibres; 3 — honeycomb core of Nomex; 4 — graphite fabric; 5 — Kevlar fabric (285)
(b): 1 — glass fibres; 2 — graphite strips; 3 — core with glass fibres; 4 — bonding agent; 5 — Nomex core; 6 — graphite fabric; 7 — Kevlar

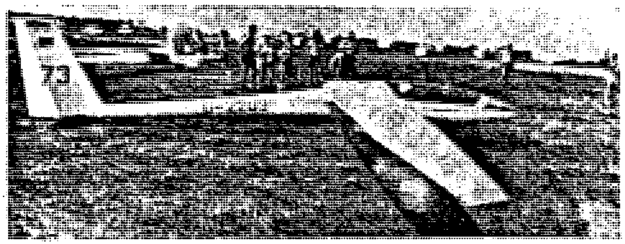


Fig. 22 The AS-W 33 all-composite glider

It is noteworthy in this connection that in 1982 the McDonnel Aircraft Company alone produced 22680 kg of long-fibre composites, while in 1986 the figure is expected to be 181500 kg; this indicates the exceptionally rapid development of these materials.

Composites are uncompromisingly and victoriously making their way into other, less exclusive industries, especially the vehicle industry.

Leaf springs (Fig. 23) and coil springs (Fig. 24) made from C/EP or hybrid composites (Figs. 25, 26) have outstanding properties. Propeller shafts made from composites have proved to be excellent (Fig. 27). Hybrid composites have been used for the side panels and spoilers of the F 1 Williams FW 9713 racing car. Composites with Kevlar fibres have been successfully used; for example, the bodywork of the BMW M 1 (Procar) was 40% lighter without loss of strength; the load-bearing members of lorries using the hybrid composite C/Kevlar/EP are stronger than steel ones and give a 60% weight saving; in speedboats fuel savings of up to 50% are achieved; canoes are 35% ligher than with glass laminate.

Ford have produced an experimental car using C/EP composite. The weight is 1135 kg instead of 1700 kg with steel, i.e. 45% reduction (sic; Ed.). On account of the high cost of this car, further development must be based on the hybrid systems C/glass/Kevlar and other resins which permit commercial manufacture, which itself has to be developed. The advantage is the smaller number of parts; for example, the wing of the Ford car made from composites has 4 main and 3 additional parts, instead of 9 parts in a steel wing, and the radiator housing has 4 main and 2 additional parts compared with 15 parts for steel (Fig. 28). This also applies to integrated floor constructions. Bonded joints are exclusively used throughout the car. Fig. 29 shows how it is envisaged that the cars will look in respect of the use of composites, in the near future.

Fibre composites are starting to be used in the construction of machinery, e.g. paper-making rollers, textile machinery, machinery operating in an aggressive environment, and machine with high speeds and rotating masses etc. (Fig. 30).

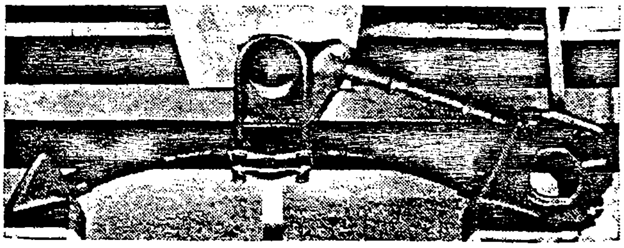


Fig. 23 Leaf spring, from a hybrid composite, for current models of car

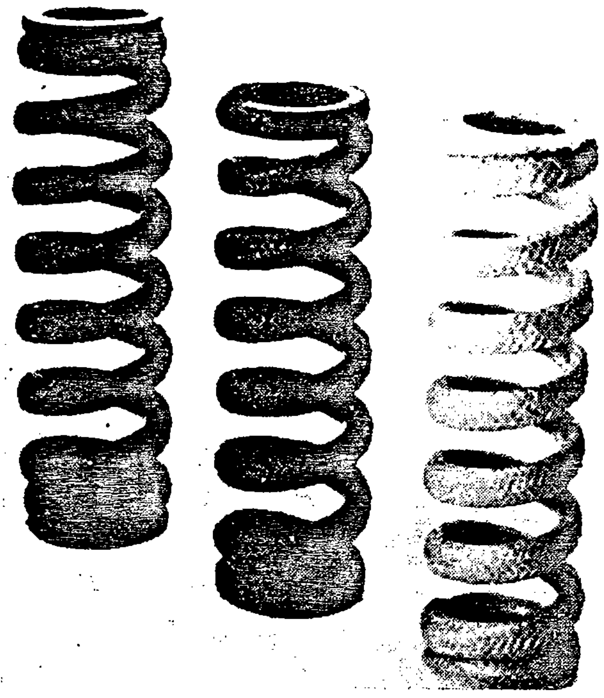


Fig. 24 Coil springs from a hybrid composite

Composites clearly also have promise in the sphere of consumer goods. For example, top-quality sports equipment (golf clubs, tennis racquets, skis) are now normally made from hybrid composites (Fig. 31). Composites also permit the construction of much lighter total ortho-replacements (with 50% weight saving) (Fig. 32).

Composites are also becoming used in the manufacture of musical instruments, as is shown by the example of a C/EP violin (Fig. 33). The production time is one-quarter of that for wooden violins; the cost of the material is lower, they are much stronger, almost unbreakable; they are not affected by moisture, temperature or ageing, and according to experts their tone is equal to that of the most famous hand-made violins.

Particulate and hybrid composites

Composites are, of course, becoming indispensable in mass production in less exclusive directions and areas, but in respect of production volume the predominant types are filled thermoplastics and fillers bound with thermosetting plastics; the fillers may be particulate (granular or flake-type), short-fibre or hybrid, and the most important matrices are the high-strength types.

Thermoplastics reinforced with carbon fibres have excellent properties: with 30% of fibres tensile strength values exceeding 140 MPa and an elastic modulus of 10 GPa are normally attained. It is possible, however, to attain more than 25 GPa (in flexure) with tensile strength of 420 MPa, i.e. the elastic modulus is more than twice that for glass reinforcement,

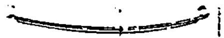
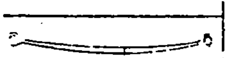
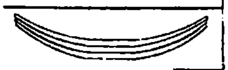
Type of vehicle	Arrangement of spring	Load capacity, kN	Spring constant, N.mm⁻¹	Weight saving, required	No. of leaves
Cars		5.8	19.3	40	1 steel 1 composite
		5.8	19.3	70	1 composite
Vans		13.3	35/78.8	50	1 steel 4 composite
Lorries		71.2	245.2	70	5 composite
		106.8	1225.9	70	5 composite

Fig. 25 Typical composite leaf springs

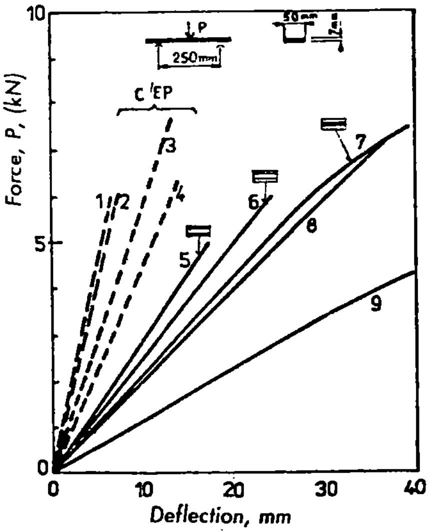


Fig. 26 Flexural working graphs of different composite springs: 1 — spring steel; 2 — type 1; 3 — type 4; 4 — type A; 5 — surfaces C/EP, core glass/EP; 6 — sandwich C/E-glass/E; 7 — glass/EP with a middle layer of C/EP; 8 — drawn, glass/EP; 9 — glass/EP laminate with layers ±45%

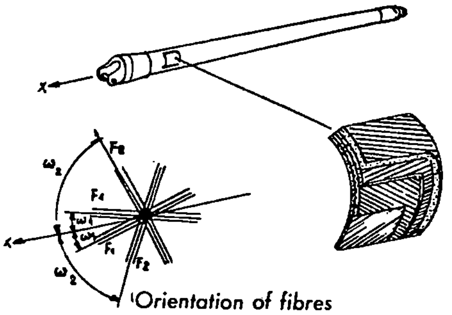


Fig. 27 Scheme of a drive shaft from a hybrid composite with two types of fibres in four directions (in two mutually perpendicular systems)

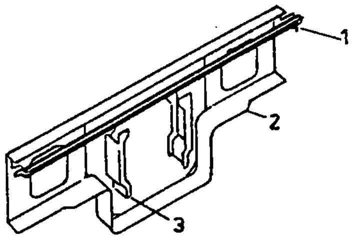


Fig. 28 Scheme of an integrated radiator block from composite: 1 — upper bracket; 2 — main construction of the block; 3 — side brackets of the radiator

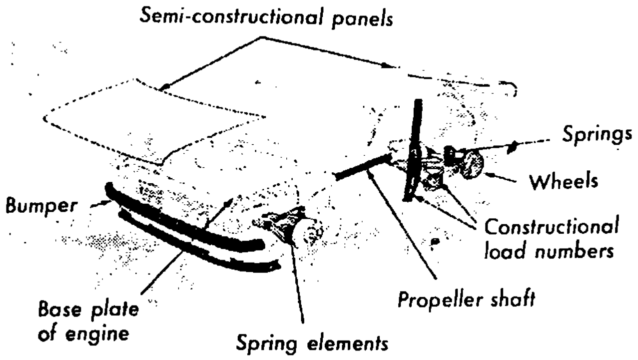


Fig. 29 Representation of the use of fibre-containing polymeric composites in the construction of a car

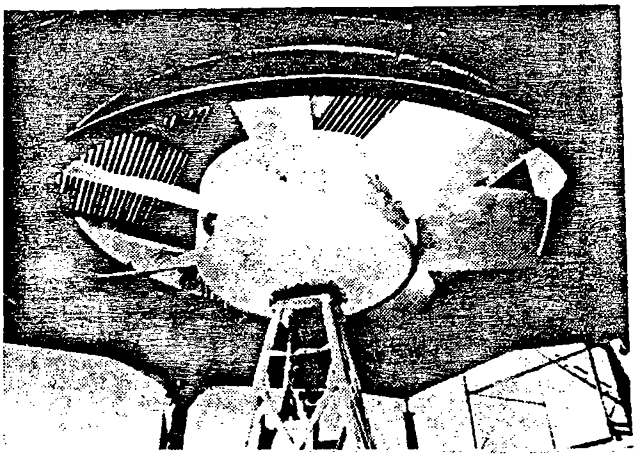


Fig. 30 Example of a rotor from a fibre-reinforced polymer

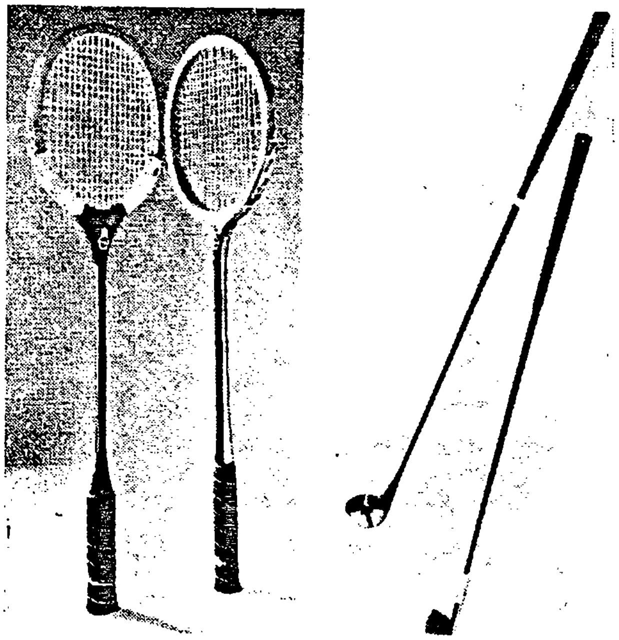


Fig. 31 Hybrid constructions of sports equipment:
a — racquets with a handle from a carbon-polymer/glass-polymer/ wood combination; b — golf clubs with a handle from a carbon-polymer/glass-polymer combination

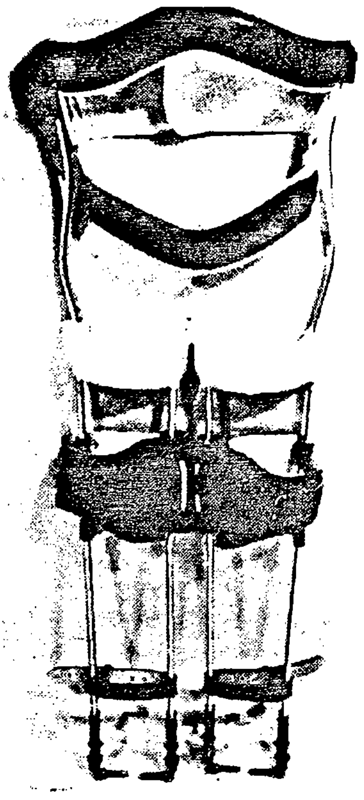


Fig. 32 Complete ortho-replacement from a hybrid carbon composite

the tensile strength is as for cast metals (cast iron, zinc, aluminium, magnesium), and the elongation at break is 2%, with excellent dimensional stability, high tribological properties, and good electrical conductivity. To give a specific example, nylon 66 reinforced with 30% of Grafil A short fibres from Courtaulds has the following properties: density 1280 kg/m^3, tensile strength 241 MPa, flexural strength 351 MPa, flexural elastic modulus 20 GPa, elongation at break 3—4%, tensile stress at a relative elongation of 0.2% = 50 MPa, and coefficient of thermal expansion $10 \times 10^{-6}K^{-1}$. Hybrid systems are also very suitable for the brake linings, e.g. phenolic resins — asbestos — C fibres, with which modern aircraft are generally fitted.

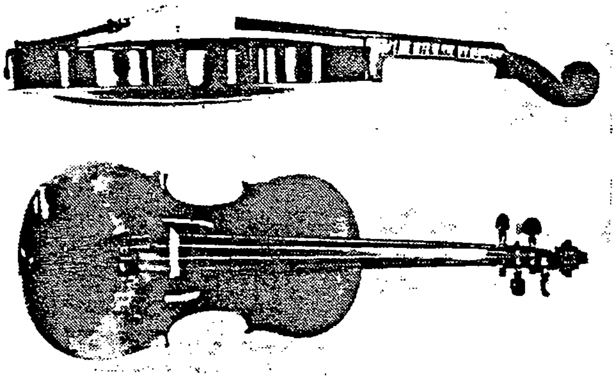


Fig. 33 Violin from carbon-epoxide composite

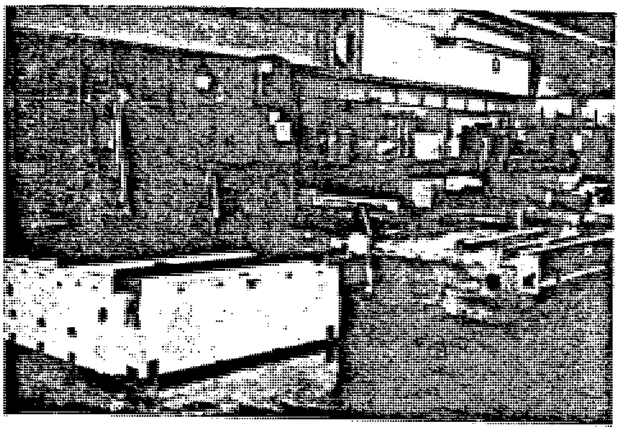


Fig. 34 Bed of a lathe, from epoxide plastic-concrete

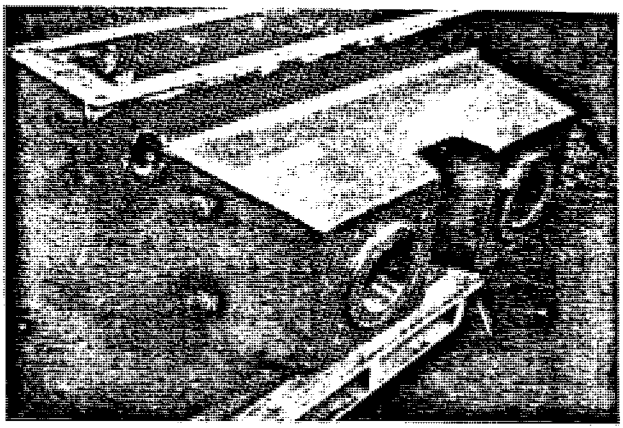


Fig. 35 Gear box from an acrylate plastic-concrete

The use of particles of water for filling of plastics permits variation of their conductivity according to the concentration of particles in a wide range, e.g. from $10^{-12}\Omega^{-1}$ to $1\Omega^{-1}$ with a volume fraction of particles of 0.5236.

A filler bound by suitable thermosetting plastics (with a minority content (by mass) of binder between 1:10 and 1:15) gives a material which can successfully compete with cement-concrete, ceramics and cast iron, in respect of mechanical properties, and can give certain improved properties (higher chemical resistance, higher damping of dynamic impulses, higher thermal insulating capacity, lower weight etc.).

The use of these materials has been normal for a long time in the building industry and in certain cases is indispensable; in engineering there is an increase in the production, for example, of beds for lathes and other machines (Fig. 34), gear boxes (Fig. 35) etc. with replacement of metallurgical products (e.g. grey cast iron).

(No References)

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