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Advances in Materials Technology: MONITOR

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REINFORCED PLASTICS

Dear Reader,

This is number 26 of UNIDO's state-of-the-art series in the field of materials entitled Advances in Materials Technology: Monitor. This issue is devoted to the subject of **REINFORCED PLASTICS**.

The plastics/composites industry is one of today's most rapidly developing industries. Use of plastics and advanced structural composites is increasing because these materials offer benefits over alternative materials in many applications of lighter weight and increased performance. The main article for this Monitor has been written for us by Dipl.-Ing. Wilhelm Grimm, Austria.

We invite our readers also to share with us their experience related to any aspect of production and utilization of materials. Due to paucity of space and other reasons, we reserve the right to abridge the presentation or not publish them at all. We also would be happy to publish your forthcoming meetings, which have to reach us at least six months prior to the meeting.

Throughout this Monitor excerpts and extractions appear from proceedings published by SAMPE. SAMPE - Society for the Advancement of Material and Process Engineering, P.O. Box 2459, Covina, California 91722, USA.

Industrial Technology Development Division

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A. Current review of the state-of-the-art

The technology of composite materials - specifically, reinforced plastics - has significantly progressed since the early 1940s, at which time the high-structural- strength Reinforced Plastics (RP) were developed.

Although initially hindered by the relatively high cost of raw materials and slow, expensive processing methods for the more sophisticated parts, the RP industry grew rapidly in the past years rapidly (see table 1: 1991 Consumption of Japan and US).

At the present time, such significant advantages are being made in the development of materials with excellent properties (strength, modulus) that the possible future applications will require the implementation of faster and more efficient mass-production techniques.

Characteristic features of reinforced plastics are the materials resp. components and the processing technologies.

A.1 Materials

A composite is a combined material created by the synthetic assembly of two or more components:

- The reinforcement material (commonly fibre material)
- A compatible matrix binder (commonly resin systems)
- A core material

Typical reinforcement materials include:

- Glass fibre E-, S-, R-Glass
- Carbon fibre HT, HM, IM
- Aramide fibre HT, HM.

Semi-finished products of fibre materials are:

- Chopped fibres
- Strand mat
- Woven fabric
- Multiaxial layers
- Rovings and yarns

Typical resins include:

- Thermoplastics
- Thermoset materials

Typical core materials include:

- PU-Foam
- Nomex-Honeycomb
- Al-Honeycomb

A sheet-shaped semifinished product combined of reinforcement fibre and resin system is called "prepreg" (pre-impregnated material).

A wide range of combinations and types is available for specific applications:

Matrix system	Fibre reinforcement	Fibre types
Epoxy	Unidirectional rovings	Glass
Phenolic	Woven fabric	Carbon
Polyester	Strand mat	Aramide
Thermoplastics	Fleece	Polyester

1991 Consumption of Japan and US (1,000 tons)

		Japan	US
Unsaturated polyester	Total	251	492
RP use		202	375
Non RP use		49	117
Reinforced polyester		445	639
Epoxy resins	Total	166	195
RP use		58	35
Non RP use		108	160
Reinforced epoxy		159	98

Table 1: 1991 consumption of Japan and US

Reinforcement fibres

		E-Glass	S-Glass R-Glass	Aramide KEVLAR	Carbon HT	Carbon HM
Density	g/cm^3	2.56	2.59	1.45	1.75	1.81
Tensile strength	kN/mm^2	2.5	3.7	2.9	2.8	1.8-3.0
Tensile modulus	kN/mm^2	73	85	130	220	300-500
Elongation at break	%	3.5	5.5	2.1	1.6	0.8

Table 2: Reinforcement fibres, types and properties

Resins (Thermoset)

		Epoxy	Polyester	Vinylester
Density	g/cm^3	1.2	1.2	1.15
Tensile strength	N/mm^2	75	60	65
Tensile modulus	kN/mm^2	4	3	3.5

Table 3: Resin systems, types and properties

Thermoplastic matrix systems

		PP	PA 66	PEEK
Density	g/cm^3	0.9	1.14	1.3
Tensile strength	N/mm^2	40	65	100
Tensile modulus	kN/mm^2	1.4	2.0	3.8

Table 4: Thermoplastic matrix systems, types and properties

Core materials

		PU	Nomex	Al-Honeycomb
Volume weight	kg/m^3	50-300	29-144	16-192
Tensile strength	N/mm^2	75	60	65
Compress. strength	N/mm^2	2-14	0.4-12	0.2-15

Table 5: Core materials, types and properties

For press-moulding processes and injection moulding special compounds consisting of reinforcement fibres and resin systems are available.

A wide range of combinations and types is available for specific applications:

Matrix system	Fibre reinforcement	Fibre types
Phenolic	Chopped fibre	Glass
Polyester	Cut woven fabric	Carbon
Thermoplastics		Silica
Epoxy		

Structural design of composite piece parts is an iterative process which starts with trade-offs of various conceptional designs utilizing different materials.

Since the material commonly is built up from a number of individual layers, each oriented in a given direction, each particular element of the material within the structure can theoretically be designed to be optimum for a number of design conditions (load, structural weight, ...).

For design and stress analysis of composite piece parts laminate properties are relevant.

A.2 Technologies

Reinforced plastics are a combination of a resin matrix, fibres, fillers and core material, which, when cured, produce a solid structure.

The characteristics of the desired end product (such as size, shape, quantity) determine the method by which the basic materials are combined, moulded, cured and machined.

A.2.1 Moulding

<u>Hand lay-up technique (laminating)</u>

Starting with a mould (usually female) the moulder applies a pigmented coating called gel coat.

The structure of the part is built up on this coating and consists, usually, of glass reinforcement (chopped strand mat, woven fabric) and resin (epoxy or polyester).

After curing the item is removed from the mould and will be finished at the exterior side.

<u>Spray-up moulding</u>

Gel coat is applied to the mould.

Design Properties of Unidirectional Composite Material (Laminates)

Reinforcement: Resin: Fibre content:		E-Glass Epoxy 60%	Carbon HT Epoxy 60%	Aramid HT Epoxy 60% by vol.
Density	g/cm^3	2.1	1.6	1.35
Tensile strength	N/mm^2	900	1 600	1 300
Tensile modulus	kN/mm^2	35	130	80
Flexural strength	N/mm^2	900	1 600	600
Flexural modulus	kN/mm^2	35	120	50
Compress. strength	N/mm^2	600	1 500	250
Interlaminar shear	N/mm^2	28	90	40
Elongation at break	%/mm^2	3.5	1.2	2.2
Coefficient of Th. Exp.	10-6K	8	0	-4

Table 6: Design properties of undirectional composite material (laminates)

Design Properties of Multiaxial Composite Material (Laminates) Reinforcement: Woven fabric				
Reinforcement:		E-Glass	Carbon HT	Aramid HT
Resin:		Epoxy	Epoxy	Epoxy
Fibre content:		50%	50%	50% by vol.
Density	g/cm^3	1.9	1.6	1.33
Tensile strength	N/mm^2	400	580	520
Tensile modulus	kN/mm^2	25	70	30
Flexural strength	N/mm^2	500	800	350
Flexural modulus	kN/mm^2	22	120	20
Compress. strength	N/mm^2	350	700	80
Interlaminar shear	N/mm^2	28	55	35
Elongation at break	$\%/mm^2$	3.5	1.4	1.7
Coefficient of Th. Exp.	10-6K	11	5	0

Table 7: Design properties of multiaxial composite material (laminates)
Reinforcement: woven fabric

Glass reinforcement is chopped in short strands and sprayed onto the mould along with the resin system.

Resin injection moulding (RTM)

The reinforcement, without the resin, is loaded into the mould, the mould is closed (male and female mould), and the resin is injected or transferred into the mould, in such a manner as to completely impregnate the enclosed reinforcement material.

A press is not required.

Application of vacuum can support resin flow and impregnation.

Press moulding (SMC, BMC, ZMC)

Products made by the "thermoset matched die moulding process" constitute half of all reinforced plastic parts manufactured at the present time.

Reinforced materials are bulk moulding compounds (all ingredients are combined in an intensive mixing process) and sheet moulding compounds (thin, semi-tacky preimpregnated sheets of glass strand mat).

Complex shapes with rips and cut-outs can be made.

Filament winding

It is an operation in which continuous reinforcements in the form of rovings are wound over a rotating mandrel.

Specially designed CNC machines, traversing at speeds synchronized with the mandrel rotation, control the winding angles and the placement of the fibres.

The resin is to be applied on the dry roving during the winding stage (impregnation bath between fibre creel and filament winding machine). Normal curing on the mandrel is conducted at an elevated temperature in a curing cabinet.

Pultrusion

This technique is for the manufacture of constant cross-sectional profiles (pulling, extrusion).

In a line the oriented fibre package (rovings, woven fabric strips, strand mat strips) is consolidated dry, then impregnated in an impregnation bath with thermoset resin, pulled with hydraulic pullers (clamps) through the heated dye and cut with an on-line saw unit.

Prepreg lay-up (vacuum bag and autoclave moulding)

This is a method for placing continuous and short preimpregnated fibre filaments in proper orientations and consolidate within the plies of a complex composite structure.

Prepeg (unidirectional tapes or woven fabric made of glass, carbon or aramid fibre impregnated with thermoset resin) has to be laid-up on the tool following the lay-up table of the manufacturing documents.

The composite material has to be covered with a bleeder system and a vacuum-proof bagging film.

Vacuum connections are placed and the film is sealed to the mould plate.

The bagged mould is transferred to an oven or autoclave for curing with full vacuum applied (and pressure for the autoclave process).

Complex shapes, including double contours and sandwich structures, and relatively large parts are readily handled.

A.2.2 Curing

<u>Mould curing</u>

Hand lay-up technique (laminating), spray-up moulding and resin injection moulding (RTM) will commonly be combined with mould curing at room temperature.

The exothermic nature of polyester and epoxy resins results in a cure in shorter time than might be expected.

<u>Press curing</u>

BMC and SMC material will be cured in metal moulds under heat and pressure.

Mould temperatures are in the range of 100-160°C.

Moulding pressures are in the range of 1.5-3.5 MPa.

<u>Curing in ovens, even with vacuum</u>

Hand lay-up technique (laminating) and filament winding commonly requires curing in an oven at temperatures in the range of 60-190 C.

Sophisticated parts (e.g. for aircraft industry) will be cured in a vacuum bag for air bubble-free consolidated structural parts.

Filament wound parts commonly will be cured on rotating mandrels.

<u>Autoclave curing</u>

Piece parts made of prepreg technology shall be cured by simultaneous application of temperature, vacuum (inside the bag) and pressure (outside the bag).

Curing temperature is in the range of 80-220°C, vacuum in the range 50-500 mbar abs, pressure in the range of 1.5-8.0 MPa.

A.2.3 Machining, surface treatment, bonding

Composites, like other structural materials, must be joined and machined to create useful structures.

The manner in which these processes are performed is a determining factor in the efficiency and suitability of such components.

Mostly used machining operations of composite parts are contour trimming (routing) with diamond coated tools or using waterjet or laser cutting.

Drilling, milling, countersinking and grinding are to be done with special tools and using fixtures or templates.

Typical surface treatment is the application of primer for a following bonding operation (composite-composite, composite-metal) and lacquering of finished parts.

Assembling operations are bonding and/or riveting.

B. Industrial applications

B.1 Construction and building

Examples	Materials	Processes
Corrugated roof slabs	Glass strand mat Polyester	Continuous press moulding
Cladding panels	Glass strand mat Polyester	Laminating vacuum injection
Tension rods	Glass roving Polyester	Pultrusion
Distribution boxes (telecommunications)	Glass strand mat Polyester	Vacuum injection SMC press moulding
Sanitary cabinets, bath tubs	Glass strand mat Polyester	Resin transfer moulding Spray-up moulding
Waste water pipes	Glass roving Polyester	Filament winding

B.2 Automotive and vehicle

Examples	Materials	Processes
Drive shafts	Glass roving Carbon roving Epoxy	Filament winding
GFRP-leave springs	Glass roving Epoxy	Pulforming
Spoilers, bumpers front ends	Glass strand mat Polyester	Resin injection SMC press moulding
Engine hoods	Glass strand mat Thermoplastics	GMT press moulding
Racing cars monocoque	Carbon fabric Epoxy	Hand lay-up

B.3 Plants for chemical industry

Examples	Materials	Processes
Containers, vessels	Glass roving Polyester	Filament winding
Pressure vessels	Glass roving Aramid roving Epoxy	Filament winding
Tubes, pipes	Glass roving Epoxy	Filament winding
Clearing basin covers	Glass strand mat Polyester	Hand lay-up

B.4 Sports industry

Examples	Materials	Processes
Fishing rods	Glass roving Epoxy	Pultrusion
Tennis rackets	Glass fabric Carbon fabric Epoxy	Press moulding
Surf boards	Glass fabric Epoxy	Vacuum moulding
Masts	Glass fabric Carbon fabric Epoxy	Filament winding

B.5 Marine

Examples	Materials	Processes
Boat hulls	Glass fabric Carbon fabric Epoxy	Hand lay-up
Safety-buoys	Glass fabric Epoxy	Vacuum moulding

B.6 Electrical appliance

Examples	Materials	Processes
Insulating parts	Glass roving Epoxy	Filament winding
Insulating parts	Glass chopped Fi. phenole	BMC press moulding
Special cases	Glass strand mat Polyester	SMC press moulding
Distribution boxes	Glass strand mat	Vacuum injection moulding
Slot wedges	Glass roving Polyester	Pultrusion
Printed circuit boards	Glass fabric Epoxy	Press moulding

B.7 Aerospace industry

Examples	Materials	Processes
Skin panels Elevators Rudders Radomes Wings Flaps Covers	Glass-, carbon-, aramid prepreg Epoxy Nomex honeycomb Al-honeycomb Foam core	Autoclave moulding
Tanks	Glass roving Aramid roving Epoxy	Filament winding
Struts	Carbon prepreg Epoxy	Prepreg lay-up
Rotor blades	Glass-, carbon-, epoxy prepreg Foam core Honeycomb	Tool moulding
Floor panels	Glass-, carbon-, aramid prepreg Nomex honeycomb	Prepreg lay-up Autoclave curing

B.8 Mechanical engineering

Examples	Materials	Processes
Cylinders Rolls Shafts Couplings Spindels Robot arms Lengthening pieces Coverings	Glass roving Carbon roving Glass fabric Carbon fabric Epoxy Polyester Thermoplastics	Filament winding Press moulding

C. Future trends in development of raw material

Reinforced plastic technology is becoming less a matter of regional development and application and more a connecting point for diverse interests in world-wide joint ventures and business opportunities.

More manufacturers seek access to new markets and new applications.

Globalization of markets mandates that suppliers of raw materials and fabricators of piece parts have access to technologies that meet product needs world-wide.

This effects the need in standardization of raw material as well as of manufacturing processes.

The cost aspect will be more important in the future.

An increasing economic aspect is environmental protection, which leads to harder regulations of trade boards regarding pollution during production and the task of waste disposal and recycling.

The cost increase caused by this must be compensated by optimum manufacturing efficiency.

New developments in raw materials and additives will support this important matter.

C.1 Thermoset material

Low shrink tooling resin

As an innovation in the field of tooling resins polyester systems will be offered with low-profile additives with room-temperature cure that is claimed to yield low shrink and low stress in moulds.

So mould-making can generally be done for much less cost than with conventional grades and give fabricators the economy to justify low-volume parts.

Air-release agents

It is an additive for polyester resins to reduce the need for vacuum application to remove air bubbles (for example for densified marble).

New catalysts for rapid-production shops

It achieves room-temperature cure or faster barcol hardness, so parts can be demoulded in as little as 20 minutes, versus up to 60 minutes with conventional catalysts.

Low-profile additives to upgrade surface quality

Materials would find use in SMC for fabrication of exterior automotive body panels.

Gel coats for building and marine parts

Benefits are that they provide a high degree of stain, salt and water resistance. They will offer greater blister and improved clarity and resistance to chalking and yellowing combined with improved flexibility.

Low-styrene-emission resins

LSE polyesters will be used for their benefits in reducing shop emissions.

Besides Scandinavia interest has only lately begun increasing in Europe and the Middle East.

It will be more and more important for fabrication of large-scale and mass parts (marine, automotive industry).

Flame-retardant grades of bulk moulding compounds

This material is formulated to meet recently enacted safety standards from underground and rail transit systems.

PUR scrap used as coring material in RIM panels

Granulate from the scrap of reinforced polyurethane reaction injection moulded parts can be incorporated into sandwich panels made in the structural RIM process.

Epoxy-based prepreg system curing at room temperature

This material can be made up with various types of reinforcement, including fabrics and multi- and uni-axial webs and tapes, in glass, carbon, aramid and hybrids.

Prepregs are drapable and can be processed by vacuum bagging, autoclave and in presses.

Material must be stored in cold storage (-18°C), the shelf life at 23°C is four hours.

Cure reaction produces no volatiles.

C.2 Thermoplastic composite material

Drapable composite sheets

Drapable and consolidated rigid composite sheets with 50 per cent glass fabric commingled with different thermoplastics in different weaves are intended for parts as bumper beams, seat shells, sports helmets.

Carbon-loaded PS and PC

The product is an amorphous, low-shrink polystyrene formulated with superconductive carbon loading to achieve electrically conductive material.

It is for controlling electrostatic discharge in packing, electronic housing and other EDS-sensitive applications.

New sizing (avivage) for carbon fibre reinforced thermoplastics

Using carbon fibre with modified size (thermoset as well as thermoplastic) results in better adhesive force between fibre and resin system and increases therefore mechanical properties of laminates (flexural strength, shear strength, compressive strength).

D. References

Modern Plastics International, January 1992; Handbook of Composites, 1982, Edited by George Lubin; Preprint 24th International AVK Conference 1991, Berlin; Vetrotex Textilglas Report 1991.

E. Coming events in RP technology

19-20 March 1992 Würzburg, Germany	International Conference on Thermosets. Congress Centre
24-26 March 1992 University of Newcastle-upon-Tyne, United Kingdom	FRC'92. Fifth International Conference on Fibre Reinforced Composites
24-27 March 1992 New Delhi, India	Polymer Processing Society's Eighth Annual Meeting/ Conference
1-2 April 1992 Mannheim, Germany	Plastics in Automotive Engineering. Conference Centre
7-10 April 1992 Bordeaux, France	ECCM-5 Fifth European Conference on Composite Material. Palais des Congrès
9-12 April 1992 California United States of America	Thirty-seventh International SAMPE Symposium, Anaheim Convention Centre
9-14 April 1992 Osaka, Japan	JP'92. Plastics and Rubber Fair
22-24 April 1992 Paris, France	JEC'92. Journées Européennes des Composites. Palais des Congrès
11-13 May 1992 Hamburg, Germany	Thirteenth SAMPE Europe. Congress Centre
1-3 July 1992 Wiesbaden, Germany	VERBUNDWERK'92. 4. Internationale Composite Messe. Rhein-Main-Halle
23-25 September 1992 Dornbirn, Austria	31. Internationale Chemiefasertagung. Kongresshaus Dornbirn
29 October - 5 November 1992 Düsseldorf, Germany	K '92. Internationale Messe Kunststoff und Kautschuk. Messegelände

2. APPLICATIONS

Fibre reinforcements for plastic composites

As demand for reinforced plastics and composite materials expands, improvements in fibre reinforcements continue. Glass fibre is the most widely used and cheapest reinforcement for plastic products. A new sizing formulation for glass fibres improves the mechanical properties of unmodified polypropylene by increasing the interfacial adhesion between the reinforcement and resin. With the new reinforcement, the tensile strength of polypropylene is increased by 20 per cent to 30 per cent and the heat-deflection temperature by 15 per cent. Cost savings can be achieved in some formulations since the glass content can be reduced to achieve desired properties.

A major study concluded that long glass fibres are better in structurally demanding applications for polypropylene and nylon 6 reinforced plastics. Long fibre moulding compounds are more efficient in reinforcing the matrix, enhancing load-bearing ability at high temperatures.

Spunlace polyester fibre added as a surfacing veil to plastic composites improves corrosion resistance, thermal shock, abrasion resistance, and resistance to ultraviolet radiation. It also offers advantages in pultrusion and filament-wound plastic composites.

Graphite or carbon fibres were found to significantly improve corrosion resistance of plastic composites compared to glass fibres. Since the resin matrix is the principal resistor of corrosion in reinforced plastics, once the resin is permeated, corrosion attack on the fibre can cause composite failure. Carbon fibres were found to be more inert to a wide variety of corrosive chemicals at elevated temperatures.

Carbon fibres with triangular, star, or other unusual cross-sectional shapes are now available. Fibres are produced by a novel melt-assisted spinning process with a broad spectrum of shapes and mechanical properties that can be tailored for high performance aerospace and industrial applications.

A hybrid engineering textile fibre is comprised of an aramid and carbon fibre. It has the high impact resistance and tensile strength of aramid and the high modulus and stiffness of graphite.

Silicon carbide fibres comprised of beta-silicon carbide crystals with excess carbon are produced by a proprietary pyrolysis process from rice hulls. The fibre is readily wet by resins and metals for good composite adhesion and unlike carbon fibre is nonconductive. (Source: Annual Report on High-Tech Materials - Technical Insights)

* * * * *

Acoustic emissions reveal fibre matrix bond strength

Estimates of the strength of the bond between the matrix resin and the fibre reinforcement in polymer-matrix composites (PMCs) can be made by a simple-to-use non-destructive technique recently patented by Wen-li Wu, a scientist at the National Institute of Standards and Technology (NIST), Gaithersburg, Maryland. In Wu's method, laser energy heats a very small area of the composite specimen. The resulting thermal expansion between fibre and resin causes debonding to occur, which produces a measurable acoustical emission. In general, the stronger the interfacial bond, the weaker the acoustical signal. The technique also can be used to gauge interply strength in PMCs. Conventional methods of evaluating bond strength are tedious to perform, and require highly skilled personnel and special test specimens or destruction of the composite.

How it works

For most composites, the reinforcement and matrix materials have different coefficients of thermal expansion (CTEs). As a result, heating or cooling can cause debonding at the interface due to the build-up of thermally induced stress. The difference in CTEs is pronounced in PMCs. For a given combination of matrix and reinforcement, the temperature at which debonding occurs depends on the strength of the bond at the interface: the greater the strength, the higher the temperature.

The new NIST method also can be used to monitor the interply strength. In a PMC, all the fibres within a ply are oriented in the same direction. This orientation direction changes only between plies. For a given ply, thermal expansion occurs mainly at directions perpendicular to the fibres. What results is a mismatch in the direction of preferred thermal expansion between plies, which can induce large interply thermal stresses and lead to failure.

Debonding events in both instances are monitored by an acoustic-emission detector. Instead of measuring the thermal stress, which depends on the local temperature and local temperature gradients, the laser-power level at which debonding occurs is taken as an index of the debonding stress.

The detected debonding emission signal (or signals) can be correlated to thermal-power levels in a number of ways, including amplitude of the emission signal, acoustic-event counts, total acoustic energy, rise time, and duration. In the examples shown here, the area under the acoustic-signal curve (the total acoustic energy) is plotted against laser power to reveal information about the fibre/matrix interfacial strength of graphite-reinforced epoxy and polyphenylene sulphide (PPS).

Typical test data

The heat source used for these tests was a continuous-wave argon-ion laser. Using a lens of 60 mm (2.4 in.) focal length, the beam was focused on the top surface of the composite specimen for 5 seconds. The acoustic signal was detected by a Series 3000 sensor both during and after the heating period. The sensor was positioned 50 mm (2 in.) from the laser-heated spot along the fibre direction of the top ply.

The plots of total acoustic energy against laser power indicate that composites with weaker interfaces yield higher acoustic outputs. However, cautions NIST, this finding may only be proof that the method can be used to detect different interfacial/interply strengths. In some instances the relationship between debonding strength and accustic output may be just the opposite.

The first example compares the total acoustic energy released by two 12-ply graphite/epoxy composites having 0°/90° ply orientations. The matrix material in both composites is a commonly used epoxy, consisting of a stoichiometric mixture of a diglycidyl ether of bisphenol-A and metaphenylene diamene. The reinforcements are the polyacrylonitrile (PAN)-based graphite fibres AU-4 and AS-4. The fibres differ only in their surface treatments. The interfacial shear strengths of the AU-4/epoxy and AS-4/epoxy composites are 37 and 68 MPa (5,400 and 9,900 psi), respectively.

The data reveal that the minimum laser power required to create an acoustic signal is 2 W for AU-4/epoxy and 4 W for AS-4/epoxy, and that the acoustic-energy level is higher for AU-4/epoxy at all levels of laser power. Thus, for the composites in this example, the one with the weaker interface (AU-4/epoxy) is much "noisier".

Two unidirectional composites are compared in the other example: AU-4/epoxy and AS-4/polyphenylene sulphide. Although both composites are known to have poor interfacial strengths, the data indicate that the AS-4/PPS specimen is inferior to AU-4/epoxy.

Competing methods

Sonic scanning techniques are used to detect voids and cracks at interfaces in PMCs, but they cannot measure the strength of interfacial bonds. Dynamic mechanical tests also have been tried, but the results are not conclusive.

Laboratory methods of estimating interfacial-bond strength include micro-indentation tests (which push in the fibre), fibre pull-out tests, and single-fibre coupon tests. However, all are said to be time-consuming and tedious, and to require the preparation of special test specimens. NIST also points out that these methods cannot be easily adapted to "real-world" composites.

Finally, other optical and acoustic methods have been used to detect certain pre-existing flaws, debond areas, and compositional variations in PMCs. But, explains NIST, these methods were not designed to cause debonding at fibre/matrix interfaces or interply regions, or to determine bond strengths. (Mr. Wen-li Wu, B320 Polymer Building, National Institute of Standards and Technology, Gaithersburg, MD 20899, USA. Tel.: 301/975-6839) (Extracted from Advanced Materials & Processes, August 1991)

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<u>Resin flow through fibre reinforcements during composite processing</u>

Researchers in the composite industry have begun to use several advanced manufacturing processes to reduce the cost of producing fibre reinforced composite structures. Resin transfer moulding (RTM) is becoming an increasingly popular composite process because of its fast cycle time, low labour requirements and low part cost. The first step in an RTM operation is to fill a mould with various fibre reinforcements in one or more orientations. The actual resin transfer process begins after the mould is closed. Resin flows around and through the fibre network until the material is saturated and the mould is filled. Injection pressure, flow rate and gate locations are important variables to consider before designing and building the mould and installing process controls. In a more automated and efficient variation of RTM, the injection-pultrusion process, dry reinforcement materials are continuously pulled from their spools and preshaped using a series of guides. They then move through preheaters and are compressed as they enter the pultrusion die. Injection-pultrusion differs from the traditional wet bath approach in that matrix materials are injected directly into the die. This greatly increases the range of matrix materials that can be pultruded, and has a number of quality, health and safety advantages as well.

A common problem encountered with these manufacturing processes is poor impregnation of the fibre reinforcements. The impregnation process is affected by many factors such as the mechanical properties of fibre reinforcements, surface tension between resin and fibres, and distribution of fibre volume in the fibre reinforcements. Resin impregnation has a dominant effect on the final micro-structures (void ratio) and the performance of composite parts.

A common goal of these processes is to increase wetting and eliminate voids in order to improve product quality. Better understanding and prediction of the wet out process is an important prerequisite for an engineer wishing to optimize and control the process. Although numerical and experimental analysis of resin filling in the RTM process had been performed by many researchers, not much is known about the fundamental characteristics of the resin flow in the fibre reinforcements.

Conclusions

Resin flow through fibre reinforcement has been studied. It was found that flow behaviour is dependent on several parameters. These include: (1) fibre structure, (2) fibre volume fraction, (3) resin saturation, and (4) flow rate. Flow pattern may change as fibre volume fraction is changed. An empirical permeability model has been presented based on the compression study. Experimental data fits well with predictions. The prediction of flow should consider interface effects when V_f is less than initial fibre volume fraction, V_0. As fibre volume fraction increases, interface effects decrease. Multilayer permeability can be predicted based on the compressibility data and single permeability data. (Excerpts from the 22nd International Society for the Advancement of Material and Process Engineering (SAMPE) Technical Conference, 6-8 November 1990, article written by specialists from University of Lowell, USA and American Composite Technology Inc., USA)

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<u>Pitch-based carbon fibre-reinforced polyethernitrile composites: improvements in fibre/matrix interfacial properties</u>

A new engineering thermoplastic resin polyethernitrile (ID300) was combined with a continuous pitch-based carbon fibre (CF). Impregnation was accomplished directly from the powder form to a well consolidated prepreg. The prepreg sheet was utilized in the diaphragm sheet forming method to produce hemispherical geometries. The pitch-based carbon fibre was treated by oxidative solutions in order to increase the bonding properties of CF to ID300. As a result of the treatment, an increase of both interlaminar shear strength and transverse flexural strength was obtained. Interlaminar fracture toughness (G_{IC} and G_{IIC}) were also increased due to the surface treatment.

The melting behaviour of ID300/pitch-based CF composites was measured by DSC using quenched and annealed samples.

ID300 is a semicrystalline polymer with both high heat-resistance and excellent chemical resistance. The glass transition temperature (Tg) and the melting point (Tm) of ID300 are 145°C and 340°C respectively.

As a reinforcement fibre, a pitch-based CF was employed. The pitch-based CF used in this study (IPCF) has excellent handling properties particularly for braiding, weaving, and prepreging. Because of its flexibility, IPCF was readily combined with ID300 by a powder impregnation method. Several studies have been conducted regarding pitch-based CF/thermoplastic systems.

In the case of a semicrystalline polymer, its morphology and mechanical properties depend on the thermal history during processing. Because ID300 is a semicrystalline polymer, to examine melting behaviour of the ID300/IPCF composite is valuable. The melting behaviour was measured by differential scanning calorimetry, using quenched and annealed samples.

During the thermoforming of advanced thermoplastic composites, there are some techniques used such as matched-die press forming, diaphragm forming, and rubber pad press forming.

Conclusions

A new engineering thermoplastic resin (ID300) was combined with the pitch-based CF (IPCF). Powder impregnation was performed and no fibre bundle damage occurred in this process. That is, IPCF has excellent handling ability and has proven to be suitable for the powder impregnation process. After the hot-press process, prepregs were successfully obtained, and consolidation was found to be excellent. In addition, polymeric diaphragm forming using ID300/IPCF prepregs was carried out, and hemispherical shapes were successfully formed. These results show CF reinforced ID300 is readily applicable to the forming process of complex shapes. This formability of ID300/IPCF prepregs can be attributed to excellent ID300 flow properties, which has been demonstrated in injection moulding processes.

From the DSC measurements, the melting point of ID300/IPCF was found to be 338°C and a second small melting peak was found. As a result of quenching and the study of quenched and annealed samples, it appeared that the small melting peak shifted to the higher temperature position as the annealing temperature increased. This result suggests that secondary crystallization took place during the annealing process.

ID300/IPCF composite was shown to exhibit excellent fibre dominated properties. Through fibre surface oxidation, the bonding properties of IPCF on ID300 was improved and a significant increase in interlaminar fracture toughness by the surface treatment of IPCF was demonstrated. (Excerpts from 36th International SAMPE Symposium, 15-18 April 1991; article by Masaaki Itoi and Yukiharu Yamada, Idemitsu Kosan Co. Ltd., Central Research Laboratories, 1280 Kami-Izumi, Sodegaura Kimitsu, Chiba, Japan and R. Byron Pipes, Center for Composite Materials, University of Delaware, Newark, DE 19716, USA)

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Environmental performance of glass fibre reinforced PPS advanced thermoplastic composites

Abstract

An improved glass fibre reinforced PPS thermoplastic composite material system (AVTEL)® was introduced at the 35th International SAMPE symposium in 1990. These composite materials contain E-glass unidirectional roving, woven fabric or random mat impregnated with semi-crystalline poly(phenylene sulphide) (PPS). The PPS polymer is a specially optimized composite grade resin characterized by high toughness and morphological structure of benefit to composite properties. This composite grade resin is well adhered to the glass fibre surface via a specially designed sizing. The resultant system achieves excellent fibre dominated as well as resin dominated properties.

This dramatically improved poly(phenylene sulphide) composite material system leads to improved retention of properties under hot/wet environmental conditions. PPS resin is little affected by hot/wet conditions and this good behaviour can be translated to the composite material via appropriate sizings. PPS/glass composites absorb minimal levels (approximately 0.1 per cent by weight) of water when exposed to hot/wet environments of 71°C, 95 per cent humidity until saturation.

Even though the new composite exhibited improved properties, it was felt that applying a sizing over an already sized glass might not provide the best overall composite properties. An effort has been established to apply the proprietary sizing directly to the fibres. This glass has been successfully prepregged and the properties of the composite laminates are presented in this paper.

Water transport theories in composites

Degradation of mechanical properties of composites after exposure to wet conditions is not well understood. An early study evaluated chopped fibre glass compounded in a polyester resin with water soak conditioning at 20, 60 and 100°C. The first response of the composite was swelling caused by the absorption of water. By means of optical microscopy, separation of the resin from a clean (no sizing) glass surface was observed. Sizing agents provided improved adhesion of the resin to the glass and no separation was observed in the compounds during the swelling phase of immersion. At longer immersion times in hot water, the polyester resin exhibited a pronounced shrinking, reported to be caused by leaching of low molecular weight material. This shrinkage, along with the environmental effects on the glass itself, was enough to destroy the adhesion even with sized glass fibres. The mechanism of debonding is speculated to be caused by osmotic pressure at the glass interface. The pressure gradient is a result of soluble metallic ions leaching from the glass.

Water absorption has also been investigated in epoxy matrix resins and the corresponding glass and carbon fibre reinforced composites. The water absorption of the composites at high humidities was about 15 per cent lower than for water soaked exposure. Water absorption was also found to decrease as the humidity decreased. The total amount of water absorbed was found to be independent of the volume fraction of epoxy resin (with one exception). Higher absorptions were observed than would be predicted based on the neat polymer's water absorption. Most interesting was the observation (by microscopic examination) that the water was able to penetrate to the interface and debond the matrix. Subsequently, an attempt was made to determine the uniformity of the absorbed water in the composites using capacitance measurements. The analysis indicated that the water in the matrix resin was present as disks which could bridge between the interface of fibres (where there is a high concentration of water) allowing a conduction path throughout the composite.

Results

Moulding process and dry composite properties

The composite prepreg was prepared using a proprietary process. Fibre weight per cent was nominally 68 per cent (54 volume per cent). Unidirectional laminates were prepared by press moulding 10 plys (to give a final thickness of approximately 0.15 cm) of prepreg using the following moulding cycle: 10 minute contact at 329°C; apply 1.4 MPa (200 psi) for 15 minutes at 329°C; transfer to cold press at 1.7 MPa (250 psi) and 20°C. The laminates were allowed to reach room temperature in the cold press and then annealed at 200°C for two hours in a convection oven. Press moulded laminates were also used for all of the hot/wet testing.

Thermoplastic composite laminates can be reheated and thermoformed to a desired shape. These laminates are typically made in an autoclave. A standard autoclave cycle for PPS/glass unidirectional prepreg consolidation is as follows: put the bagged composite into the autoclave; apply vacuum followed by application of 68.9 kPa (10 psi) pressure; heat to 273°C (525°F) and hold for 40 minutes; continue heating to 329°C (625°F) and when reached, apply 965 kPa (140 psi) pressure; hold for 15 minutes; cool at 11°C per minute and depressurize at 149°C (300°F).

Humidity conditioning

Longitudinal tensile strengths were measured for laminate specimens exposed to 95 per cent relative humidity at 71°C. The composite retained 81 per cent of its initial strength and the modulus was virtually unchanged after 14 days; after which time increased water absorption and further property degradation was not observed. Total water absorption was approximately 0.1 per cent. It is interesting to note that the water absorption of the PPS composite is nearly identical to the water absorption of bare glass fibres. This would indicate that the water is present at the interface of the composite, which would be expected since PPS absorbs minimal amounts of water.

Immersion conditioning

In some applications, immersion (in water or in brine solution) is more representative of application conditions. In the following series of tests, the conditioning of specimens was done at 49°C in brine solution. The strength retention is 84 per cent even after six weeks' exposure. If the specimens are dried, 100 per cent retention is observed. The modulus is virtually unchanged for all conditions. Longitudinal flexural properties exhibit similar behaviour. The strength retention after six weeks is 73 per cent and after drying is 84 per cent.

Conclusions

Improvements in PPS/E-glass composite materials make them more suitable for applications requiring high performance thermoplastic composites. These improvements include a tough matrix resin and a proprietary sizing applied directly to the glass surface. The material is commercially available and is marketed under the AVTEL[R] trade name. Laminates made from this improved PPS/fibre glass prepreg have good retention of properties after exposure to high humidity or immersion in brine and provide a significant improvement over the original PPS/fibre glass system. (Excerpts from 36th International SAMPE Symposium, 15-18 April 1991, article written by D.A. Soules, R.L. Hagenson and P.J. Cheng, Phillips Petroleum Company, Bartlesville, Oklahoma 74004, USA)

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Stress rupture behaviour of natural fibre-reinforced composite materials

Abstract

Studies have been done in the development, performance and application of natural fibre-reinforced composite materials. However, should this class of composites be considered for structural applications, its long-term performance under sustained constant load needs to be evaluated. As such, this project involves the investigation of the stress rupture behaviour of abaca fibre-reinforced composite material. The abaca fibre, which is used as reinforcement in a proportion of polymer matrix, is a natural fibre extracted from abaca plants. Fabrication of the composite is by conventional hand lay up method. Specimen, saw cut from the fabricated lamina, is installed in a gripping fixture designed for stress rupture application. Composite lamina with short fibre volume fractions of 30 per cent and 40 per cent are used in the experimental investigation which is carried out to establish the influence of fibre volume fraction on the stress rupture life. The results show that both lamina fail by stress rupture. An increase in sustained constant stress reduces the life of the abaca fibre-reinforced composite materials. On the other hand, the rupture strength of the material increases significantly as the fibre volume fraction increases. The rate of degradation under sustained constant stress is higher in material with less fibre volume fraction.

Experimentation

Material

The natural fibre of vegetable origin is cellulose, a substance made from glucose molecules, bound to lignin and other varying amounts of natural materials. The vegetable fibre is classified according to the part of the plant where the fibre occurs and from which the fibre is extracted. Abaca fibre, also known as Manila hemp, falls under the leaf fibre category. The fibre is extracted from the leaf sheaths of the false stalk or "trunk" of abaca plants (Musa Textillis Nee) of the banana family. Its structure is multicelled and its chemical composition is mostly cellulose: 83.18 per cent holocellulose and 54.33 per cent alphacellulose. In addition, it also has some amount of lignin - 9.88 per cent and ash - 1.98 per cent. The fibre strands of abaca are composed of 4 to 200 cells or optimum fibre as part of its fibro-vascular system. The shortest fibre length is 2.36 mm, while the longest is 9.14 mm. The multicelled fibre is rectangular in cross section and has a fibre length that varies from 1 m to 3 m. The thermosetting matrix is a proportion of thiokol, araldite and hardener.

Fabrication and preparation

Abaca fibre is cut to approximately 20 mm in length which is the compromise length of short abaca fibre as a consequence of obtaining better tensile and impact properties. Any bent strand of fibre is discarded. Only straight strand is utilized. The short fibre in direct contact with each other is then laid up on the bottom mould in layers with one end of the fibre being at the middle of the fibre length of the underlying layer. The fibre is deliberately aligned in the direction of loading (unidirectional). The matrix proportion is then distributed evenly on the top of the fibre. Then the top metal mould is mounted on the top surface of the layers of fibre prior to the application of compressive pressure. The pressure is applied in a manner in which thickness uniformity is maintained throughout the lamina, until the desired thickness is achieved. The specimen is then saw cut from the fabricated lamina having 30 per cent and 40 per cent fibre volume fraction. The fibre is weighed and the weight fraction is converted to volume fraction.

Conclusion

From the experimental investigation, the following conclusions are drawn: (1) Just like any other material, abaca fibre-reinforced composite material is also susceptible to failure by sustained constant static load application. (2) Abaca fibre reinforcement improves stress rupture time. (3) The higher the fibre volume fraction the better is the long term performance of the material. (4) There is good potential for abaca fibre-reinforced composite material for structural application if maximum fibre volume fraction is used in the composite design. (Excerpts from 36th International SAMPE Symposium, 15-18 April 1991, article by Benjamin C. Tobias, Department of Mechanical Engineering, Victoria University of Technology (FIT Campus), Ballarat Road, Footscray, Victoria, Australia, 3011)

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Mechanical behaviour of bidirectional intraply hybrid laminates

Abstract

This investigation deals with the tensile properties of composite laminates constructed from a new class of bidirectional fabrics which preserve a near zero-crimp state, i.e. a non-interlocking feature of the warp and fill tows. Tensile tests are performed on carbon/glass, glass fibres and carbon fibres reinforced epoxy, confirming that the elastic properties of bidirectional intraply hybrids can be predicted accurately with the help of micro-mechanical equations in conjunction with the laminated plates theory. Similarly to single-fibre bidirectional laminates, the stress-strain response of the bidirectional intraply hybrid laminates is constituted of two linear portions due to the failure of the transverse plies. However, the failure pattern of the bidirectional hybrid laminates is different from that of single-fibre laminates. No hybrid effect is detected and the failure stress can be predicted with the fibres' maximum elongation model.

Introduction

Due to their cost efficiency and good manageability, woven fabric reinforced plastics have been used for many years in a variety of applications ranging from boats to semi-structural aircraft components. However, woven fabrics present poor mechanical performance as compared to prepregs. This limitation is due to the interlocking feature of the fill and warp fibre tows. Given its long experience in the weaving process, many textile industries have proposed solutions to avoid this limitation. Among the various types of reinforcement that can be produced are unidirectional and bidirectional fabrics that preserve a near zero-crimp state, i.e. a non-interlocking feature of the warp and weft tows in the composite structures. These fabrics have the advantage of conforming easily to complex shapes and they are sometimes called high-modulus or no-crimp fabrics.

An additional way to optimize the properties of composite structures made with no-crimp fabrics is to use two or more types of fibres in the same layer. We thus obtain a so-called intraply hybrid cross-ply laminate, where the term hybrid is used to denote the incorporation of different fibre types in a common matrix. With this hybridization, it is possible to further enhance the tailoring features of the fabrics, since intraply hybrids have unique characteristics that can be used to meet diverse design requirements in a more cost-effective way than conventional fabrics.

Conclusion

Results obtained in the study show that the elastic properties and strength of a complex fabric configuration can be predicted satisfactorily by using simple models in combination with the laminated plate theory.

Furthermore, for this bidirectional fabric, we can make these general observations:

- The elastic properties are proportional to the amount of each constituent;

- The knee-point strain increases with the addition of carbon fibres;

- The fracture stress of the hybrid specimens is much lower than that of its constituent;

- The first fibre breakage of the hybrid specimens is controlled by the maximum strain of the less extensible fibres.

Using the ultimate strength as a criterion for the choice of a reinforcement does not obviously favour the hybrid fabric over the all-glass fabric. But other design considerations such as stiffness and weight can overcome these disadvantages. (Excerpts from the 22nd International SAMPE Technical Conference, 6-8 November 1990, article written by Andre Benard, Rachid Boukhili and Raymond Gauvin, Department of Mechanical Engineering, Ecole Polytechnique de Montreal, P.O. Box 6079, Station "A", Montreal, Quebec, Canada, H3C 3A7)

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Centres for development of technology of plastics composites and product application

The technology of composite materials, comparatively new even in industrially advanced countries, should prove especially valuable for the development of less advanced countries that have a large labour force. Composites technology is labour-intensive and science-based, and provides materials with physical, chemical, mechanical and electrical properties that offer a very wide range of applications.

The term "composite" or, alternatively, "plastic composite" is usually taken to refer to fibres or reinforcing materials surrounded by matrix resinous or plastic substances resulting in properties superior to those of the non-reinforced substances. These materials are usually known as reinforced plastics or fibre-reinforced plastics, laminates or filled moulding compounds. Typical composites are:

(a) Fibreglass reinforced plastics: commonly used as a structural material with a wide application in housing, tubing, containers, boats and vehicles;

(b) Carbon (graphite) reinforced plastics: widely used in the aerospace field, transportation, boat construction and industry. They are characteristically as stiff and strong as steel but five times as light;

(c) Aramid (Kevlar) reinforced composites, a fibre similar to glass but not self-abrasive: widely used in tyre reinforcement, hoses, engine beltings, ropes, aircraft applications and electrical products.

UNIDO can help in procuring specialized equipment for producing, fabricating and testing these materials. It can provide training by foreign specialists, and it can place selected nominees for fellowships within the industry. It can organize instructional tours by senior personnel to industrial plants in highly-developed countries, and it can arrange international conferences and workshops at which foreign scientists and personnel from developing fibres and plastics industries can meet and exchange information.

In India, the Centre for Development of Technology of Fibres, Composites and Product Application was founded with the assistance of UNIDO. A centre for fibre technology is now at an advanced stage of planning in Brazil, where it will serve the national aerospace industry. Other centres are expected to follow. (Excerpt from a UNIDO publication "UNIDO for Industrialization")

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Fibre composite with thermoplastics

A new fibre composite material for aeronautics has been developed by Dornier. It is a carbon fibre reinforced thermoplastic CF/PEEK, where the PEEK is a polyether ether ketone. For processing existing composites of this type the carbon fibres are woven together to sheets and soaked in the synthetic resin components. As the matrix of this kind of prepreg production epoxy resins are overwhelmingly used - they belong to the group of thermosetting plastics. According to the property required, the resin type can be varied in order to produce the desired matrix system. For the new CFK material, a matrix system has been introduced that does not consist of thermosetting material, but uses modern thermoplastics. A CFK-prepreg with a thermoplastic matrix of this kind is claimed to be different from that using thermosetting material, in having better impact toughness, higher extension at break, better resistance to erosion and to higher temperature. In contrast to the thermosetting plastics, the thermoplastics can be melted and can be pressed like metals, welded or deep-drawn.

Since thermoplastic prepregs are not sticky and therefore cannot be draped in forms, the materials engineers have had to work on new methods of finishing and processing. Using infrared radiant heaters and heating gas plants the processing cycles can be considerably shortened compared with those for fibre reinforced thermosetting plastics. (Dornier GmbH, Postfach 1420, 7990 Friedrichshafen 1, Germany. Tel.: 07545/8 38 93. Telex: 734209-0 do-d. Fax: 07545/8 44 11) (Source: New Materials World, February 1990)

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Polyetherimide fibre for resistance to flame and chemicals

Polyetherimide (PEI) resins such as General Electric's Ultem have been widely recognized for their excellent heat and flame and chemical resistance in moulded parts and, more recently, film form. Teijin America has now announced the availability of PEI in fibre form. This amorphous thermoplastic fibre features a limiting oxygen index of 47, long-term thermal index (ULI) of 170°C, and mechanical properties similar to those of rayon fibres. The new fibre also demonstrates good resistance to a wide range of chemicals, except concentrated alkalis and halogenated solvents, and is highly resistant to weather and hot water.

The new PEI fibre is anticipated to find wide industrial use in filters, sealing materials, brushes of various kinds, and in a large number of composite materials. Cowoven and intermingled and other novel combinations of PEI fibre and reinforcement fibres offer a wide range of readily available drapeable yarn, tow, and fabric forms. (Teijin America Inc., 10 Rockefeller Plaza, Suite 1001, New York, NY 10020, USA. Tel.: +1 212 307 1130; Fax: +1 212 307 6042) (Source: New Materials World, August 1991)

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Temperature performance of plastic matrix composites improved

UBE Industries has introduced a new type of polyimide for plastic matrix composites. It has a high tackiness at 100°C and at room temperature, good stability, a low curing temperature (standard cure below 290°C), a high glass transition temperature, observed near 250°C, and a high mechanical strength.

This polyimide was developed for plastic matrix composites. Reinforced with UBE's Tyranno fibres, Upiam based composites have higher flexural strength than carbon fibre reinforced polyimide. High glass transition temperature close to 300°C is obtained without postcure.

Although matrix degradation can often be observed on the surface after composites are heated at 600°C, the fibres are not damaged at all with the Tyranno fibre reinforced polyimides. The imide oligomer investigated in the research has good solubility in polar organic solvents and is also curable at relatively low temperature. These advantages bring easy prepregging and result in excellent processing. The composites are promising as structural materials in aircraft and aerospace industries. (UBE Europe, London. Tel.: +44 71 930 7377; Telex: 884394; Fax: +44 71 839 2751) (Source: New Materials World, August 1991)

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Fibre-reinforced composite material for forming complicated shapes

Asahi Chemical Industry Co. Ltd. has developed a fibre-reinforced composite material that can be melted by heating for producing products with complicated shapes.

Convention composite materials usually use a thermosetting resin and are inconvenient as reshaping and forming into complicated shapes are quite difficult since the material is brittle. The company mixed a fibrous heat melting resin with reinforcing fibres such as carbon fibre and glass fibre, and produced a fibre-reinforced composite material that is flexible and can be bent in any direction.

This material is called Web Interlaced Prepreg (WIP) and uses carbon fibre or glass fibre as the reinforcing material. These fibres are aligned in parallel and interlaced at the individual filament level with short fibre resin, such as nylon 6, nylon 66, polyphenylene sulphide (PPS) or polyether ether ketone (PEEK), depending on the specific use.

Shaping WIP at high temperature melts the resin and causes it to wrap the reinforcing material (such as carbon fibre) to provide a very strong composite material.

Nylon and polyethylene terephthalate (PET) are ideal for producing industrial parts and sports/leisure goods, and PEEK and other engineering plastics for large products such as aircraft structural materials.

Present composite materials such as those made of carbon fibres almost all use thermosetting epoxy resins and have to be stored at low temperatures before shaping to prevent resin hard curing. Also, a fixed period of time is necessary for hardening after moulding. (Asahi Kasei Carbon Fiber Co. Ltd., Marketing & Sales, 1-1-1, Uchisaiwai-cho, Chiyoda-ku, Tokyo 100. Tel.: +81-3-3507-7874; Fax: +81-3-3507-2498) (Source: JETRO, September 1991)

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High-temperature thermoplastics

A family of thermoplastic resins introduced by Amoco Performance Products is based on polyphthalamide (PPA) chemistry to bridge the gap between high utility engineering resins such as nylon and polyester and the more exotic and expensive liquid crystal polymers and polyetheretherketones (PEEK). The semicrystalline Amodel PPA technology is unlike any previously available chemistry, and offers excellent physical properties, outstanding dimensional stability, and very broad process flexibility. The initial Amodel product includes neat (unreinforced), glass, mineral and glass/mineral reinforced, flame retardant, and impact modified grades.

The resins are easily moulded, without flash or mould corrosion, may be vapour phase and infrared soldered, and may be plated with hard chrome or soft brass metals. They melt at 310°C, and provide continuous use at 185°C - superior to similarly reinforced polyester, polyphenylene sulphide, Nylon 66, polyetherimide (PEI), polybutylene terephthalate, and acetal compounds. The mechanical properties are also outstanding. The main glass reinforced compounds show 32 ksi tensile strength and 45 ksi flexural strength.

The Amodel resin family is expected to find rapid application in gears, hose and tubing, seals, wire and cable (unreinforced applications), gears, bearings, and other industrial parts (glass reinforced); chrome platable plumbing fixtures and reflectors (mineral reinforced); small engine components, ignition parts, and power tools (glass/mineral compounds); caster wheels, clips and fasteners, and power tools (impact modified); and electrical/electronic components, connectors, switches, sockets, and circuit breakers (flame retardant glass reinforced). (Amoco Performance Products, 375 Northridge Road, Atlanta, Georgia 30350-3297, USA. Tel.: +1-404-621-4557; Fax: +1-404-512-6700) (Source: New Materials World, June 1991)

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New composite sandwich fire barrier

A growing awareness of flame/smoke/toxicity (FST) problems with polymeric and composite materials, along with heightered regulatory control of materials in aircraft and other transportation applications, has led to the development of a wide range of materials for protective applications. Ciba-Geigy has introduced a series of composite sandwich panels, called Cibabarrier, for use in non- and semi-structural applications. The panels are made up of graphite or glass skins of various weights and weaves, combined with phenolic resin. The cores are of Nomex aramid or glass.

These constructions have a smoke value of less than 10/10 OSU and 15 D smoke values, and produce only 0-30 per cent TOX gases as defined by ATS 1000. High barrier compositions provide direct flame burn-through protection to 1100°C, while maintaining OSU values of less than 25/25.

The mechanical properties of these panels are somewhat modest, however, having only 900 psi sandwich compression in a single wall sandwich, and only a 450 lb short beam shear strength. Structural panels are under development. (Ciba-Geigy Composite Materials, 5115 East La Palma Avenue, Anaheim, CA 92807, USA. Tel.: +1-714-779-9000; Fax: +1-714-777-0628) (Source: New Materials World, June 1991)

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"Simpler than glass fibre" reinforcing technique developed

A new polymer reinforcing technique which involves mixing a hard polymer with a soft polymer has been developed by researchers at Sophia University's Faculty of Science and Technology. In tests, p-hydroxybenzoic acid was added to a solution of styrene-butadiene rubber (SBR) and mixed in a homogenizer at 2,500 rpm. At the same time, polymerization was catalyzed by the addition of triphenyl-phosphine, hexachloroethane, and pyridine, to produce a composite polymer of liquid crystal (LC) polyester (a hard polymer) distributed uniformly through the SBR, which is a soft polymer.

The composite polymer was then dissolved in toluene and a polymer film was formed by casting. A film containing 25 per cent LC polyester had twice the tensile strength, and an elastic modulus 40 per cent greater than 100 per cent SBR. The researchers believe that the new technique is much simpler to use than conventional glass fibre reinforcing techniques. (Sophia University, Chiyoka-ku, Kioicho 7-1, Tokyo, Japan. Tel.: +81-3-3238-3111) (Source: New Materials World, August 1991)

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Spectacular performance claimed from polymer fibre for composites

A new family of the ultrahigh molecular weight polyethylene fibre Spectra has been introduced for use in composite applications. Lighter than aramid fibres (e.g. Kevlar, Twaron) by 30 per cent, its specific gravity is only 0.97. It is also exceptionally strong (tensile strength is 434 ksi) and high in modulus (tensile modulus is 25 Msi), giving it an unsurpassed strength-to-weight ratio. Further, with its 2.20 dielectric constant and loss tangent of 2×10^{-4}, it is the most electronically transparent synthetic fibre available.

Fully compatible with industrial resin standards of vinyl ester (Dow Derakane 411-45), epoxy (Shell Epon 826), and isophthalic polyester (Ashland Aropol 7240), the Spectra 1000 products also provide impact absorption more than 20 times that of glass, aramid, and graphite systems, with no catastrophic failure in the Spectra samples. (Allied-Signal Inc., High Performance Fibres, P.O. Box 31, Petersburg, VA 23804, USA. Tel.: +1-804-520-3171; Fax: +1-804-520-3388) (Source: New Materials World, September 1991)

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Strength of polyacrylonitrile carbon fibre doubled by processing

The compressive strength of polyacrylonitrile (PAN)-based carbon fibre can be doubled by implanting ions in the surface of the fibre, according to researchers at Toray Industries Inc.

In tests, 10^{13} boron ions/mm^2 were implanted in the fibre's surface. This roughly doubled the compressive strength from 370 kg/mm^2 to 700 kg/mm^2. The tensile strength was also increased (by 34 per cent), as was the torsional modulus. The compressional strength of a resin impregnated composite material incorporating the fibre was increased from 107 kg/mm^2 to 133 kg/mm^2.

Electron microscopic observation of a 7 micron diameter ion implanted fibre revealed a double layered structure in which the crystalline structure had been altered to a depth of 0.5 microns.

The company expects the new carbon fibre to find applications in sporting goods and aircraft. (Toray Industries Inc., 2-2-1 Nihonbashi-muromachi, Chuo-ku, Tokyo 103, Japan. Tel.: +81-3-3245-5111; Telex: 22623; Fax: +81-3-3245-5555) (Source: New Materials World, September 1991)

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Durable BMI composite to be used in hot/wet/tough applications

A toughened bismaleimide (BMI) composite product has been developed for applications requiring extreme toughness under hot/wet conditions at exposures up to 120°C. Still showing outstanding strength retention after 1,000 hours at 230°C, CYCOM 3135 is an excellent candidate for aircraft use.

A 24-ply layup of unidirectional tape prepregs reinforced with IM7 graphite fibre showed open hole compressive strength of 71 ksi at room temperature, and still demonstrated 41 ksi strength at 230°C. A 32-ply layup showed 36.0 ksi compression after impact strength, having been impacted at 1,500 in-lb/in. of laminate thickness. This toughness will find wide applications requiring the utmost in field durability. (American Cyanamid Co., Engineered Materials Department, 21444 Golden Triangle Road, Saugus, CA 91350, USA. Tel.: +1 (805) 259-1415) (Source: New Materials World, September 1991)

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Thermoplastic composites

Reinforced thermoplastic tapes comprise unidirectional continuous fibres in a thermoplastic matrix with fibre content to 70 per cent. Fibres include glass, aramid, carbon, and polyolefins. Resin matrix can be based on polyolefins, PVC, nylon, polyester, and similar materials. The tapes are used to make products such as pipes, pressure vessels, filament-wound structures, and pultruded sections. (BayComp, Division of Bay Mills Limited, 5035 N. Service Road, Burlington, Ontario, Canada L7L 5V2) (Source: Machine Design, 8 August 1991)

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Automated system for fibre composites

A system for production of components made of long-fibre-reinforced synthetics has been developed by the Fraunhofer Institute for Production Technology (IPT). This is a system which provides great flexibility in its application in winding and tape positioning processes with regard to the use of semi-finished products and component geometries. The basis of this system is a six-axis portal robot modified for processing and machining of fibre composites and enhanced with the necessary peripherals.

Because of low rigidity the portal robot can only be used to a limited extent for machining synthetic fibre composite components. However, machining units are under development with which simple operations such as drilling, trimming, and light cutting tasks can be performed. Whereas fibre composites are widely used in aircraft manufacture, they are only slowly gaining acceptance in auto manufacture and mechanical engineering. One reason for this is the lack of production systems with which components of high technical quality can be made both reproducibly and cost-effectively. Until now, component production has been characterized by a great deal of manual work. This is particularly true for components which are flat, spherical, or not rotationally symmetric. In contrast to the situation in aviation and space, it is first necessary to develop suitable processing and machining equipment. The IPT is working within the framework of the special research area concerned with development of cost-effective production machines.

Of the processing activities for fibre composites, winding and tape positioning procedures are particularly well suited for long-fibre processing. The functional suitability of components produced in the winding and tape positioning procedures depends on the orientation of the fibres in the composite. The complexity of the calculation algorithms for dimensioning such parts and the necessity for extremely accurate production make automation of the fibre composite design and production process essential.

This design for a flexible production system for fibre composite components developed at the Fraunhofer Institute for Production Technology points the way to a transition from the custom designs for a very limited spectrum of components available to date to versatile production. The component size flexibility obtained, the production changeover capability, and the preparation of semi-manufactured products enables the manufacturer to react more quickly to altered market conditions.

With the portal system, a group of components of varied cross-sectional shapes (cylinder, rectangle, oval) and of lengths between 100 and 2,800 mm has already been produced in the winding process. This clearly demonstrated the advantages of the flexible design. Continued research activities will focus on increasing cost-effectiveness through accompanying automation measures.

The capacity for rationalization of the production of fibre composite components depends to a critical extent on the degree of automation possible in production cycles. Consequently, a fundamental task involves the creation of the system components and data-processing conditions essential to production of fibre composites. Plans are being developed for a tool-changing system, a component core-changing system, and a palletization system for linking the forming stations to the downstream hardening stations.

Automation represents a central emphasis of this research project within the framework of cost-effective production with reproducible high product quality. A design for networking the robot control with external computer systems to form a CAD/CAM link is currently under development. (Excerpt from Frankfurter Zeitung/Blick durch die Wirtschaft, 14 August 1990)

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Plastic said to outlast steel in paper scraper

A manufacturer of advanced plastic composite materials said paper companies that use blades made of polyphenylene-sulphide resin and fibreglass can expect the blades - which act as scrapers placed along the length of a paper roller - to last longer than similar instruments made of steel.

Plastic composite blades resist the corrosive chemicals used to bleach paper, last three times longer than steel blades and weigh significantly less.

Pultruding is a process for forming continuous lengths of fibre-reinforced advanced composites.

While so-called doctor blades made of laminated fibreglass or epoxy are not new to the paper-making industry, blades made of pultruded composites offer an innovative approach to waste and cost management.

Doctor blades are thin beveled-edge scrapers placed along the 30-foot rollers on paper-making machines.

The rollers, made of cast iron or steel, graphite and rubber, normally press smooth and dry lengths of paper in precise thicknesses. In order to be efficient, the rollers must be kept free of wood pulp or chemical residue.

Synthetic doctor blades made of thermoplastic composites can increase the life of these rollers by 50 per cent.

The blades are cut from 100-foot-long pultruded polyphenylene-sulphide and fibreglass composites sheets. (Extracted from American Metal Market, 28 March 1990)

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Toughening mouldable phenolic composites

Success of phenolic composites in demanding automotive applications such as transmission reactors and brake pistons has led to increased interest in their use in other components traditionally made of metal. Some of the emerging uses, however, require greater toughness than that of currently available phenolic materials. A new family of mouldable phenolics provide impact toughness superior to that of conventional glass-reinforced phenolics while maintaining acceptable thermomechanical properties.

Compounding for toughness

Among the many types of plastics available, phenolics are the materials of choice where the end-use conditions include significant mechanical loads at temperatures in the 120 to 200°C (250 to 400°F) range. This choice is largely due to the ability of these thermosetting materials to retain their high modulus and strength and good creep resistance at high temperatures. When dimensional tolerances must be maintained over a wide temperature range, the low thermal-expansion coefficient of phenolic composites also is of importance.

The good thermomechanical properties of phenolics are derived from their highly crosslinked structure and attendant high glass-transition temperatures (T_gs). Although the inherent rigidity of this type of structure embrittles phenolics, fibre reinforcement allows them to absorb considerable impact energy before failure, and produces impact resistance comparable to that of reinforced brittle thermoplastics. Glass fibre is the most widely used reinforcement in phenolics for cost and performance reasons; advanced fibres, such as aramid and carbon, are still not cost-effective for most applications.

However, their moderate impact strength compared with the high-impact strength of metals may be inhibiting the use of phenolics in some applications. Therefore, research is aimed at improving the toughness and overall performance of glass-reinforced phenolics, while maintaining their competitive price and other attractive properties.

Some of the most significant energy-dissipative processes that contribute to the total fracture energy of a fibre-reinforced polymer-matrix composite are:

- Fracture of the polymer matrix;

- Fracture of the fibres;

- Energy to debond fibres from the matrix;

- Work needed to pull fibres from the matrix;

- Elastic energy released after fracture occurs.

The approaches used to increase impact toughness are directed toward enhancing one or more of these processes. The energy associated with each process depends on fibre and matrix properties, fibre shape, and the strength of the fibre/matrix bond. Although all of the mechanisms are operative in a given composite, one or two of them usually dominate impact performance.

Strong fibre/matrix bonding is needed for effective strengthening of the composite, and, consequently, only limited energy can be dissipated by debonding and pull-out mechanisms. With appropriate surface treatement of the fibres, moderately high impact strengths can be attained. Typical notched izod impact strengths range from 30 to 80 J/m (0.5 to 1.5 ft.lbf/in.) and unnotched Izod strengths range from about 80 to 135 J/m (1.5 to 2.5 ft.lbf/in.). However, these materials are naturally brittle and have relatively low crack-propagation resistance, so components must be designed to prevent cracks from initiating.

A frequently used method for improving the toughness of brittle materials is the incorporation of a separate elastomeric phase within the thermosetting-plastic matrix. Because the phenolic matrix is the continuous phase, its high T_g is preserved while allowing energy absorptive mechanisms to occur in the elastomer particles. Significant toughness gains have been achieved with little sacrifice in high-temperature properties or creep resistance. However, this method may have disadvantages in certain applications because the modifiers reduce modulus and strength somewhat.

Another toughening method, which is increasing in importance, is the use of longer fibres. Recent advances in compounding technology allow fibre lengths previously attainable only in bulk moulding compounds to be achieved in free-flowing granular moulding materials. Long fibres produce different failure modes and fracture paths by distributing the impact energy over a larger volume of material. These effects can increase the amount of energy needed both to initiate and to propagate a crack. Fibre lengths an order of magnitude greater than those in conventionally compounded materials have been maintained in moulded parts resulting in notched Izod impact strengths over 270 J/m (5 ft.lbf/in.). Longer fibres will produce even higher impact strength, but fibres longer than 3 mm (0.125 in.) result in larger granular size, which restricts their use to larger parts.

Toughened composites developed

The cost-effective use of mouloable composites often requires that properties be tailored to the needs of a particular application. Phenolics can be formulated to provide a wide range of properties, and their ability to be processed by a variety of methods offers the possibility of further performance optimization. Phenolic resins can readily accept high loadings (60 per cent or more) of reinforcing materials and other additives. Properties such as stiffness, strength, thermal expansion, and creep resistance can be controlled through fibre type and content, while hardness, wear resistance, and other properties are obtained by the judicious choice of additives.

Toughness characterization

While the capacity to withstand impact loading is one of the most important properties of composite materials, toughness is difficult to characterize. For example, because the crack in a notched Izod test is forced to travel in the direction specified by the test geometry, the results can sometimes be misleading. The relatively low notched results for the short-fibre phenolics point out the need to avoid stress concentrators in part designs. The high crack-propagation resistance obtained with longer fibre lengths is evident from the notched Izod test results; XF-23 has a notched Izod toughness about 2.5 times greater than RX630 with comparable fibre content.

The unnotched Izod results are influenced by the energy needed to initiate a crack and, therefore, represent a better measure of the toughness. With this test, the elastomer modified materials show significant improvements over the standard phenolics and approach the impact resistance of the long-fibre phenolic.

Generally, the drop-weight impact test more closely simulates end-use conditions because the crack is not constrained to a certain direction. Therefore, it offers a more quantitative measure of the energy required to initiate a crack. With the exception of the long-fibre phenolic, the drop-weight data show the same toughness ranking as the unnotched Izod results. Matrix toughening produces up to a 35 per cent increase in crack-initiation resistance.

While the use of long fibres alone, however, does not increase the energy required to initiate a crack over that for the short-fibre phenolic with an equivalent fibre loading, XF-23, as a result of its good crack-propagation resistance, sustains less visible damage than the short-fibre phenolics in drop-weight impact testing. Thus, long-fibre reinforcement may offer an advantage of a safer failure mode in some applications.

Thermomechanical properties

Modulus retention provides a good indication of elevated temperature performance, and the change of modulus with temperature of the toughened phenolics demonstrates that they have excellent high-temperature stiffness. Long-term performance at elevated temperatures also is important. For example, compressive creep is useful for predicting a material's ability to maintain bolt loads under simulated end-use conditions. (Extracted from Advanced Materials & Processes, October 1990)

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The production of thermoplastic composite prepreg structures by electrostatic fluidized bed application

A variety of methods have been used to manufacture reinforced plastic materials. As the mechanical requirements for reinforcement of resins have increased, the use of continuous fibres has become almost mandatory and traditional resins reinforced with short fibres have been found wanting. These methods used to produce resins reinforced with continuous fibres have included lamination techniques, the application of the melted resins to the substrate (hotmelt application), application of the resins to the substrate in a solvent solution or a predominately water-based dispersion, by pultrusion and other extruding processes and a variety of methods of direct resin application in a powdered form.

Each of these methods has both its advantages and disadvantages, either on the basis of the shortcomings resulting from the application method, the resulting prepreg material or because the physical or chemical properties of the particular resin precludes one or more of the application methods.

The selection of a particular industrial processing method is a complex decision-making process based on a variety of factors. These include technical properties of the material and the process, the amenability of the process in controlling the variables in the production process and, not least, the costs involved in the process.

A process that is technically feasible may or may not be viable, depending not only on commercial considerations but also from the viewpoint of how well the process can be controlled and the levels of skill required to operate the process as a high volume, efficient industrial process.

An assortment of dry powder processes have been proposed, some of which have been commercialized, which have been aimed at applying powdered resins to reinforcing fibres in a variety of forms. The concept of producing reinforced plastic materials in this way is attractive from a number of points of view, especially with respect to the application of thermoplastic materials.

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The use of electrostatic fluidized bed powder application methods for producing thermoplastic prepreg materials offers a flexible, non-hazardous, efficient process. The materials can be produced at significantly reduced cost with properties similar to those of materials produced by alternative processes.
(Extracted from 36th International SAMPE Symposium, 15-18 April 1991, article written by Denis R. McKay, Manager, Applied Technology, SL Electrostatic Technology, Inc., 4 Pin Oak Drive, Branford, CT 06405, USA)

3. TRENDS

New forming process for long fibre-reinforced plastic

Prof. T. Machida and his research team of the Faculty of Engineering, Tamagawa University, Japan have developed a new process for forming continuous fibre-reinforced plastics, a typical advanced composite material (ACM), called the Laminate-Bending Process. It essentially consists of laminating the plastic preform multifold, followed with pressing. The development of this process enables the material to bend into the 90° V angled product with a sharp zero radius top, impossible up till now.

The long fibre-reinforced plastic is produced by adding a long reinforcement such as glass fibre to the epoxy resin matrix. Compared with ordinary fibre-reinforced plastics (FRPs), the strength is more than five times greater. However, long fibre-reinforced plastic is very difficult to bend since the reinforcement has no ductility, so ordinarily it is laminated in flat form like sheet under its fusible condition. Therefore, it was only usable for producing aircraft wings and the bottoms of small boats which require no sharp bending.

With the Laminate-Bending Process, sheet-form prepregs are hot pressed e.g. for 2-3 minutes at a temperature of 170°C in the given cavity punch and die to obtain a series of V-shape semi-cured preforms which are designed to have the precise top radius and angle. The preforms are laminated and then cured by the reheating die to become a final thick V-angled product. The content of long-fibre of these products formed in this manner is maximum 66 per cent with ACM, and the inter-layer bond strength of the penta-(5) laminated product is 1.7-1.8 kg/mm^2, about the same as that of epoxy adhesive, so there is no anxiety about impaired adhesivity of the matrix resin. Also, the compressive delamination strength is 1.6-1.7 kgf/mm, which is equivalent to 55 per cent of the reverse bending strength of a mild steel V angle with the same thickness.

The new forming process enables bending even at sharp angles, so long fibre-reinforced plastics can now be used for producing automobile parts, electronic components and cases for home electrical appliances. In addition, by using the material together with metals, carbon fibres, aramid fibres, etc. to produce the hybrid, the range of applications will be expanded further. (Tamagawa University, Department of Mechanical Engineering, Faculty of Engineering, 6-1-1, Tamagawa-Gakuen, Machida City, Tokyo. Tel.: 0427-28-3111. Fax: 0427-28-3597 (Source: JETRO, December 1990)

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Prestressed concrete using carbon fibre reinforced plastics

Kumagai Gumi Co., Ltd. has developed a new concrete engineering method that uses carbon fibre reinforced plastic (CFRP) as the tendon (tension material) for prestressed concrete (PC). Both ends of CFRP fibres are bundled together with a newly developed fixing system.

A concrete structure was constructed with PC using CFRP to confirm the engineering method reliability through continuous observation for over one year. An opening (gate) 10 metres wide and 4.5 metres tall in a two-storey concrete building required a structure to bear the load of the second storey.

The tendon fixing system developed introduces the grout system for covering cylindrical sleeves on the terminal parts (fixing parts) of the tendon and filling grout between the tendon and a compression system for pressing the sleeves into a compact diameter. The fixing system impregnates grout between the sleeves and tendon and decreases the shear force under pressure by providing a binder layer. Stretching force can be resisted firmly by the adhesion force and compression force. As a result, it is possible to resist the stretching force accurately by using small metal fittings, and the fixing effect is over 95 per cent.

The tendons are formed with cables each of three CFRP wires consisting of seven strands and an outside diameter of 12.5 mm. A total of 18 cables were used. The tensile load of a cable is 42 tons, and each cable is about 21 metres long.

At the construction site, the wall structure was concreted and, after hardening, numerous CFRP cables were passed through sheaths (holes) opened in the concrete. After applying a tensile stress on the CFRP cables and fixing into position, cement paste was filled in the gaps by the post-tensioning method to provide residual compressive stress inside the entire concrete structure.

The CFRP material is much ligher (specific gravity about 1.5) than with conventional PC steel materials. It can be conveyed to the work site by hand for implanting inside the sheaths in the concrete structure. It has an excellent strength, and is also non-corrosive and non-magnetic. (Kumagai Gumi Co., Ltd., Public Relations Division, 2-1, Tsukudo-cho, Shinjuku-ku, Tokyo 162. Tel.: +81-3-3260-2111. Fax: +81-3-3255-4377) (Source: JETRO, April 1991)

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Reinforced polymer

Fibreloc polymer composite of glass-fibre-reinforced thermoplastic is custom extruded. Material is then automatically punched into shapes, as well as formed, notched, mitered, or drilled for industrial and commercial products. The strong durable composite can replace a number of materials such as aluminium because of thermoplastic properties including rigidity, creep, thermal expansion, chemical resistance, and flame retardance. Material can be colour matched for special needs. (Mercury Plastics Inc., Box 989, Middlefield, OH 44062, USA) (Source: Machine Design, 10 January 1991)

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High-performance aseptic plastic

Takuma Co., Ltd., Suntory Ltd., Shinanen New Ceramics Co., Ltd., and Fuji Kako Co., Ltd. have jointly developed an aseptic plastic, called ASEPLA, that has an antibacterial action (sterilization and prevention of proliferation).

Using the aseptic plastic for producing factory storage tanks and pipes carrying extra-pure water or drinking water will enable such equipment and water to be maintained in a highly sanitary condition without having to regularly sterilize the equipment. The companies plan to manufacture and market tanks and pipes made of this aseptic plastic from this spring.

Pipes, storage tanks, and intermediate tanks for pure water are equipped with ultraviolet ray sterilizers or ultrafiltration films for sterilization, removal of bacteria, and for preventing microbe proliferation; but it has been necessary to wash the bent pipes, joints, valves, and tank corners regularly with chemicals or hot water since they cannot be treated adequately with the aforementioned methods. To cope with this situation, the companies developed a functional plastic that provides antibacterial action to all parts coming into contact with water and which suppresses the proliferation of microbes in water.

ASEPLA is produced by mixing a powdered artificial zeolite - Zeomic, made by Shinanen New Ceramics and having an antibacterial property, into resins such as fibre-reinforced plastic (FRP) and polypropylene. Suntory, whose beer distilleries possess know-how on microbe proliferation inhibition and Takuma which handles water treatment plants cooperation in the aseptic plastic's development. Fuji Kako will be responsible for manufacturing tanks made of the aseptic plastic.

Tests conducted on tanks made of the new plastic showed that when water is allowed to stand in these tanks for 24 hours at 37°C, 99.999 per cent of E. coli are destroyed. (Takuma Co., Ltd., 3-23, Dojimahama 1-chome, Kita-ku, Osaka. Tel.: 06-347-9112. Fax: 06-347-9152) (Source: JETRO, February 1990)

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Composites industry striving for cost-effective manufacturing

While fibre-reinforced composites currently are accepted in aerospace, ground-transportation, biomedical, and recreation structural applications, there are formidable barriers to wider use. An approach to overcome obstacles such as poor damage tolerance and delamination resistance and high manufacturing costs is the use of three-dimensional (3-D) fibre-reinforced composite structures.

These structures have a significant amount of fibres (either woven or braided) that traverse from plane to plane, which provides load paths for out-of-plane stresses developed by bending, compression, and impact loading. Automated weaving equipment is becoming available that is capable of producing near-net-shape preforms having varying amounts of fibres in the x, y and z directions.

As the use of structural fibre-reinforced plastics (FRPs) continues to grow in automobile, truck and farm-equipment applications, parallel growth is anticipated in the use of structural reaction injection-moulded (SRIM) parts, with directed-fibre preforms, or shaped reinforcements, the best choice for use in large parts having deep draws or compound curves. Proven in the compression moulding of the type of structural composites, preforms are gaining greater acceptance in SRIM parts primarily due to the versatility, convenience, and high performance that directed-fibre preforms provide. Compared with fibreglass mat, which can thin out as it is stretched around corners of complex shapes, directed-fibre preforms are shaped approximately like the part to be moulded, allowing uniform distribution and random orientation of the reinforcement. The preform-making process also allows extra reinforcement to be added at corners and other critical locations. Automated equipment is being developed, including the use of robotics for high-volume production, which offers more flexibility, and requires less setup time than formed-mat and older, plenum-chamber preform machines. New direct-fibre preform machines also can produce large preforms (up to 4.5 m, 15 ft in diameter).

Compared with competing composite-manufacturing methods, such as sheet-moulding compound (SMC) and resin-transfer moulding (RTM), SRIM is said to provide parts having higher strength at a lower weight, with no loss in flexibility and impact resistance. In addition, the capability of making larger parts than possible with the other processes allows the integration of several parts into a one-shot mould. The automotive industry potentially can benefit from the use of integrated parts such as bumper beams, instrument panels, seating, and load floors. Urethane and isocyanate resins are most commonly used for SRIM, offering good mechanical properties. A broader range of part performance and price can be obtained using epoxy, acrylic, dicyclopentadiene, vinyl-ester, and hybrid resins.

Long-fibre reinforcements (either carbon or glass fibres) provide improved impact resistance without sacrificing modulus or processibility. Carbon fibres offer high modulus, low thermal expansion, and exceptional abrasion resistance.

Use of long fibres results in failure modes different from those occurring with short fibres because impact energy is distributed over a larger volume of material with the former. This increases the amount of energy needed for crack initiation and propagation, which translates into a safer failure mode than with conventional short fibreglass-reinforced phenolics.

While long fibre-reinforced composites offer improved properties, they create processing problems: they do not feed properly due to their high-bulk factor and there is fibre breakage as it is processed through the injection-moulding screw.

Possibly the most important factor limiting the penetration of polymer-matrix composites (PMCs) into markets dominated by traditional materials is the need for cost-effective manufacturing techniques. One group committed to this effort is the Center for Composite Materials (CCM), University of Delaware, Newark, Delaware, USA. Formed in 1974, the centre established a manufacturing-science research programme in the mid-1980s involving the areas of on-line consolidation, sheet forming, liquid moulding, textile-preform processing and injection moulding. During the past five years, CCM has brought PMC manufacturing to a science by integrating processing rather than considering manufacturing a series of isolated processing operations.

Research has resulted in significant breakthroughs in three manufacturing processes under study: in situ consolidation of thermoplastic-matrix composites using a focusable carbon-dioxide laser; forming complex three-dimensional forms from thermoplastic-matrix composite flat sheet stock; and bonding thermoplastic composites. Work is ongoing in these areas, with the goal of developing rapid, reproducible, verifiable, and economical fabrication methods for a variety of composite materials. Developments in manufacturing-science areas include:

On-line consolidation

- An automated placement head for thermoplastic-filament winding;
- A thermoplastic-pultrusion line;
- A laser-assisted tape-consolidation facility;
- An infrared-heater, tape-consolidation facility;
- A CAD/CAM package for robotic winding nonaxisymmetric, nongeodesic parts;
- Modelling of the thermal history of anisotropic filament-wound parts;
- Modelling of process-induced residual stress in filament-wound parts.

Sheet forming

- A completely instrumented, computer-controlled high-temperature-forming autoclave;
- Technology to form doubly curved parts;
- Modelling of the superplastic-deformation process applied to sheet-forming thermoplastic parts;
- Micromechanics models to predict anisotropic viscosities.

Liquid moulding

- Process-simulation software including the relationships of fully anisotropic, thermally dependent flow through porous media;
- 3-D process-simulation models for thin, shell-like cavities;
- Joining technology for different preform types;
- Application of prototype tooling technology within undergraduate design projects.

Textile-preform processing

- An automated 3-D braiding machine capable of computer-controlled two- or four-step braiding;
- Braiding ceramic fibres for potential use as preform reinforcements;
- Braiding two-dimensional (2-D) and angle-interlock fabrics using a computer-controlled loom;
- Modelling of the dynamic formation of braids;
- Modelling to predict detailed microgeometry of braided parts.

Injection moulding

- Process-simulation software including nonisothermal cure and solidification for arbitrary, 2-D shapes to predict mould-fill times, pressures, and fibre orientation;
- Rheological modelling of long-fibre, injection-moulding compounds;
- Rheological modelling of non-homogeneous flow fields, semiconcentrated fibre suspensions, and fibre clustering and bending;
- Development and verification of the rheological behaviour of highly concentrated suspensions used in injection moulding of ceramics, including "slip" phenomena at the mould walls;
- Rheological modelling of the behaviour of highly filled injection-mouldable ceramic-ceramic whisker formulations, including development of new, experimental techniques to measure whisker orientation.

Joining

- Design and fabrication of an automated resistance-welding apparatus;
- Thermal model of the resistance-welding process;
- A nonisothermal, diffusion-limited strength model for welding and laser-assisted tape consolidation;
- Establishment of the relationship between process-induced variability and performance in fusion-bonded joints;
- Establishment of a design methodology for welded thermoplastic structures.

Near-future CCM research will include continuing work in most of the areas mentioned, as well as projects in new areas. Continuing efforts will include:

- Fundamental research of manufacturing science with emphasis on experimentally validated process models for liquid-moulding/textile preforms, thermoforming, on-line consolidation, joining, and injection moulding that relate processing to performance through microstructure control;
- Interphase modelling and characterization with emphasis on tailoring the interphase;
- Fundamental research of coupling reaction or crystallization kinetics and mechanical behaviour;
- Ceramic-matrix composites processing;
- Fundamental research into the relationship of rheological behaviour to processing;
- Modelling of strength and fracture toughness of polymeric and ceramic composites.

Efforts in new areas will include research of:

- Multifunctional materials that exploit unique performance achieved via coupling of mechanical, thermal, electronic and dielectric, and magnetic properties; i.e., "smart", or responsive, materials;
- Thermal and environmental stability;
- On-line control of composites processing through the use of advanced-sensor technology and artificial-intelligence/knowledge-based systems;
- Identification and resolution of key issues involved in recycling composite materials.

Thermoplastics gaining wider acceptance

Pultrusion is one of the lowest cost manufacturing methods for producing advanced composite materials.

Thermoplastic Pultrusions' process involves very low pull forces, a characteristic that has been applied to pultrusion of ultrastiff PEEK composites reinforced with ultra-high-modulus carbon fibres. These fibres are difficult to work with and handle due to their brittleness, but the low pull forces make it possible to pultrude these materials without damaging and breaking the fibres. Structural profiles such as angles and channel sections can be pultruded rapidly and inexpensively to provide high-modulus composites having a low coefficient of thermal expansion.

Other materials R&D and product applications

Developments in silicone thermoplastic elastomers include silicone-foam composites and moulded silicone foam. High-performance composite sheet materials, called Exobloc, consist of a high-temperature silicone-foam core and either one or both outer layers made of various materials depending on service environment. Materials used as outer layers include aluminium foil (heat reflection), fibreglass (strength and abrasion resistance), ceramic cloth (high-temperature resistance), and silicone-impregnated cloth (improved weatherability and conformity). The modified closed-cell foam is non-toxic, and resistant to chemicals, ultraviolet light, and ozone.

The moulded silicone foam is the first commercially available material of its nature, and fire-resistant, non toxic, resilent moulded parts can be produced in a variety of shapes. Material density ranges from 0.25 to 0.4 g/cm^3 (16 to 25 lb/ft^3). The high-temperature and environmental stability of the material enable its use in severe underhood and under-body automotive applications. (Excerpts from Advanced Materials and Processes, January 1991)

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High-temperature thermo-plastic composites

Carbon fibre (CF) and glass fibre-reinforced thermoplastic composites have attractive elevated-temperature properties. Matrix resins include amorphous polyethersulphone (PES) and polyetherimide (PEI), and crystalline polyphenylene sulphide (PPS), polyetherketone (PEK), and polyetheretherketone (PEEK). While these high-temperature composites offer alternatives to metals in certain applications, in many instances, their selection for use in a specific application is based only on data derived at ambient conditions, and can lead to poor performance at elevate temperatures. Additional high-temperature property data are required to ensure that a material can meet performance requirements because these materials are affected adversely by short- and long-term elevated-temperature exposure, as well as by exposure to various chemicals. It is essential to build a property database representative of these conditions. To fill this information gap, ICI Advanced Materials tested amorphous and crystalline fibre-reinforced composites at temperatures ranging from room temperature to 260°C (500°F). Tensile strengths and flexural moduli were determined, as well as the effects of long-term loading, via tensile stress-relaxation tests. Chemical resistance of the composites to some organic solvents and selected automotive and aerospace fluids also was determined at room and elevated temperatures. Determination of high-temperature physical and mechanical properties, as well as chemical resistance, is expected to not only help match a material to an application, but also to identify where gaps in performance exist, which can lead to the development of hybrid resins for composites fabrication.

High temperatures hard on properties

Compared with unreinforced resins, composites reinforced with either carbon or glass fibres have much better load-bearing capabilities. The improvement in tensile properties results because, under loading conditions, the matrix transfers stress to the high-strength/modulus fibres. In the same resin matrix, carbon-fibre reinforcement provides as much as a 20 per cent improvement in tensile strength, and a 30 to 100 per cent improvement in flexural modulus over glass-fibre reinforcement. The thermal behaviour of the matrix resin, however, dictates the high-temperature performance of the composite.

The thermal behaviour of amorphous and crystalline resins is revealed by a differential scanning calorimeter (DSC) plot. Amorphous PES and PEI resins are charcterized by glass-transition temperatures (T_gs) of 230° and 217°C (446° and 423°F), respectively. The glass transition is a reversible change that occurs when the resin is heated to a certain temperature range, resulting in a sudden transition from a rigid polymer to a flexible rubber-like material or a viscous liquid. In contrast, crystalline PPS, PEEK, and PEK resins have distinct melting points of 275°, 334°, and 365°C (527°, 633°, and 690°F), respectively. They also have a "minor" T_g or other thermal transitions, which do not significantly affect high-temperature properties.

Tensile strengths (per ASTM D638) of the composites were determined from injection-moulded specimens at room temperature, 90°, 150°, 180°, 200°, 230° and 260°C (200°, 300°, 350°, 400°, 450° and 500°F). The strengths of all the materials drop at elevated temperatures, the rate and degree of loss increasing with increasing temperature and varying with fibre type and loading, and matrix material. However, composites consisting of either carbon- or glass-fibre reinforcement in the same matrix resin behave similarly.

Reinforced PEEK, PEK, and PPS composites lose tensile strength rapidly up to around 200°C (400°F), beyond which a more gradual loss occurs.

The strengths of both glass/PEK and glass/PEEK are similar to CF and glass fibre-reinforced amorphous-resin composites at 200°C (400°F). At 260°C (500°F), the 30 wt% glass/PEK composite has the highest strength of all the composites tested. Above 260°C (500°F), CF/PPS has no "effective" strength. Tensile tests were not conducted above 260°C (500°F); however, dynamic mechanical analysis (DMA) of both glass/PEK and glass/PEEK shows that they retain some mechanical strength up to 340° and 315°C (650° and 600°F), respectively.

Amorphous PES and PEI composites undergo a more steady loss of strength with increasing temperature to near their T_gs, where all effective strength is lost. The amorphous-resin composites studied offer significantly higher tensile strengths than similarly reinforced crystalline resins over a use-temperature range of 150° to 200°C (300° to 400°F). Specifically, they demonstrate higher strength at temperatures to just below their T_gs. Therefore, T_g is a critical factor in materials selection. It is important to note that when designing with amorphous-resin composites at the upper end of their use-temperature range, there is a possibility of catastropic failure if the service temperature exceeds the T_g even for a short time. In contrast, while crystalline-resin composites are not as strong near the T_gs of amorphous-resin composites, they maintain measurable strength above these temperatures.

<u>Applications dictate performance needs</u>

Good flexural modulus and stress-relaxation values are important considerations in many high-temperature applications. The rate of loss of flexural modulus (stiffness) with increasing temperature for crystalline-resin composites is more rapid than for amorphous-resin composites. For both 30 wt% glass/PEEK and 30 wt% glass/PPS, the loss in modulus occurs at a slightly lower rate than that for tensile strength. In contrast, both 30 wt% glass/PES and 30 wt% glass/PEI maintain a minimum of 80 per cent of their flexural moduli to within 30°C (50°F) of their T_gs. When considering high-temperature composites for use in short-term applications, the deflection temperature under load (DTUL) test can be used to predict performance. All of the materials tested have a high DTUL (over 200°C, or 400°F at 1.8 MPa, or 264 psi).

Engineering-thermoplastic composites behave in a viscoelastic manner under long-term loading. Good viscoelastic properties are required in applications such as insulators in electronic equipment, where the insulator must provide uniform pin-retention force, clip strength, and contact force. Viscoelastic properties are determined by measuring the stress relaxation of a material subjected to a constant strain at different temperatures (ASTM D2991).

In this evaluation, injection-moulded ASTM D638 Type I tensile specimens were initially stressed in tension at 17 MPa (2,500 psi) at constant strain. Reduction in stress was measured over time until the stress in the bar reached equilibrium under the imposed strain. Tests were conducted at room temperature, 90°, 150°, 200° and 260°C (200°, 300°, 400° and 500°F). After loading, stress drops rapidly at all test temperatures during the first hour, followed by a more gradual loss until the stress in the sample reaches equilibrium (usually in about ten hours).

In general, crystalline-resin composites undergo less stress relaxation than the amorphous-resin composites, especially at temperatures above 150°C (300°F). Both 40 wt% glass/PPS and 30 wt% glass/PES have the lowest stress-relaxation values at room temperature. Above 90°C (200°F), 30 wt% glass/PEK has the lowest stress-relaxation values. More extensive testing is required in different environments to clarify stress-relaxation performance; however, it appears that crystalline-resin composites offer the best strength retention.

<u>Dynamic mechanical analysis</u>

Another way to evaluate a composite's high-temperature performance is via dynamic mechanical analysis (DMA), a test that provides a comparison of the relative stiffness as a function of temperature. The advantage of DMA over static flexural-modulus test data is that a continuous plot of the flexural modulus versus temperature is obtained instead of values only at 30° to 55°C (50° to 100°F) temperature increments, providing a more complete picture of material performance.

Testing was conducted on injection-moulded specimens under a 1 Hz, 0.6 per cent strain using a dynamic mechanical analyser. The rate of temperature increase was 5°C/min (9°F/min).

DMA test results for crystalline-resin composites show that glass/PPS has very little flexural modulus above 260°C (500°F), but has a higher modulus than either glass/PEK or glass/PEEK from room temperature to 120°C (250°F), and from 180° to 215°C (360° to 420°F). In contrast, glass/PEEK has a modulus of 690 MPa (10^5 psi) at 340°C (650°F). When this value is normalized to the static flexural modulus, it converts to a more accurate flexural modulus of 1.55 GPa (225 X 10^3 psi). Normalization brings the DMA-determined modulus values to within a 15 per cent agreement with values obtained by static tests; this exercise is required to compensate for clamping errors and thermal-expansion effects.

DMA plots for both glass/PES and glass/PEI amorphous composites are nearly identical. The curve for glass/PES shows a small strength advantage at the high end of the test temperature range. Between 150° and 190°C (300° and 375°F), glass/PES has a higher modulus than glass/PEK, which correlates well with tensile strength versus temperature data for these two materials.

<u>Chemical resistance also important</u>

A combination of high service temperature and exposure to chemicals makes the prediction of composite performance particularly difficult, and the addition of stress further complicates the matter. In this study, samples were immersed in liquid chemicals for seven days at room temperature to provide control data to enhance the evaluation of high-temperature chemical resistance. Two sets of samples were used: one unstrained, the other strained (in flexure) at 0.25 per cent.

Room-temperature data for the change in tensile strength usually provide a basis to evaluate chemical resistance under "normal" conditions. However, for most of the composites evaluated, elevated-temperature chemical resistance is more relevant. If an application requires only that a thermoplastic composite part be self-supporting, data for unstrained tensile strength can be used to make a selection. Data for strained samples should be used, however, in selecting materials for more demanding applications.

Of the crystalline-resin composites evaluated, 30 wt% glass/PEK has the best overall chemical resistance. Only 30 wt% glass/PEK and 30 wt% glass/PEEK have at least fair performance in all automotive fluids studied, and in Skydrol 500 (an aerospace hydraulic fluid) up to 150°C (300°F) in both the strained and unstrained conditions. At 150°C (300°F), both 30 wt% glass/PEK and 30 wt% glass/PEEK suffer a loss in tensile strength when strained in oxidizing acids and bases. While 40 wt% glass/PPS has fair chemical resistance in all solvents and chemicals tested at room temperature, it has the poorest performance in oxidizing acids (nitric and sulphuric) and halogenated solvents, such as trichloroethylene and Freon.

In general, amorphous-resin composites have lower chemical resistance than crystalline-resin composites. The 30 wt% glass/PEI suffered stress-cracking when strained in gasoline at room temperature, whereas the 30 wt% glass/PES performed well at temperatures to 150°C (300°F).

Stress cracks are observed in amorphous-resin composites exposed to Skydrol 500 at all three test temperatures. In addition, the tensile strengths of amorphous-resin composites are significantly reduced when they are exposed to chlorinated and aromatic solvents. At 150°C (300°F), toluene dissolves both 30 wt% glass/PES and 30 wt% glass/PEI. Trichloroethylene also dissolves the PEI composite at this temperature. When exposed to oxidizing acids or bases, all amorphous-resin composites experience a decrease in tensile strength with increasing temperature. The effect is magnified when specimens are strained. At 150°C (300°F), 30 wt% glass/PEI dissolves in ammonium hydroxide, whereas the PES composite (both strained and unstrained) has unacceptable performance.

The hydrolysis resistance of the silane coupling agents and the glass fibres themselves also is an important factor in the chemical-resistance profile of a composite. At temperatures over 100°C (210°F), both are attacked by strong bases. At higher temperatures, nitric and sulphuric acids reduce the properties of glass fibre-sizing systems.

Hybrids can solve some problems

Penetration into new, high-performance market areas may depend on the development of hybrid polymers and composites to overcome the limitations of current thermoplastics. The application requirements for a small-appliance motor, including high strength and stiffness at service temperatures to 230°C (450°F), illustrate this materials-development approach.

The need to maintain strength and stiffness properties as high as possible at elevated temperature pointed to the use of a fibre-reinforced amorphous PES composite. However, the limitation of PES is its rapid loss in mechanical strength and stiffness - properties required to ensure a margin of safety - at temperatures between 200 and 230°C (400 and 450°F). By using a hybrid material blend containing PES and a high-T_g PES copolymer, the high-temperature properties were raised enough to meet the application requirements, yielding measurable mechanical properties at 230°C (450°F). (Source: Advanced Materials and Processes, August 1991. Article written by Kevin R. Quinn, senior applications development engineer and Carlos A. Carreno, director, Customer Applications Center, ICI Advanced Materials, 475 Creamery Way, Exton, Pennsylvania 19341; Tel.: 215/363-4500; Fax: 215/363-4749)

Thermal characterstics of thermoplastic composites

	Glass-transition temperature, °C (°F)	Melting point, °C (°F)	Minor thermal transitions, °C (°F)	Deflection temperature under load, °C (°F) at 1.8 MPa (264 psi)	Continuous use temperature, °C (°F)
Amorphous					
PES	230 (446)	-	-	215 (420)	190 (375)
PEI	217 (423)	-	-	210 (410)	180 (355)
Crystalline	-				
PPS	-	275 (527)	112 (235)	263 (505)	180 (355)
PEEK	-	334 (633)	142 (289)	315 (599)	250 (480)
PEK	-	365 (690)	156 (312)	357 (675)	-

(Source: Advanced Materials & Processes, August 1991)

4. MARKETING

Reinforced TPU

A new series of fibre-reinforced engineering thermoplastic polyurethane alloys (TPUs) marketed under the Estaloc 61000 Series is said to feature a combination of performance characteristics that make it ideal for metal-to-plastic conversions: flexural moduli in excess of 2,000,000 psi; a coefficient of thermal expansion lower than aluminium; the dimensional stability required for closefitting components; and impact resistance that is said to be five times that of materials with equal rigidity. Parts are said to not warp and to be paintable without primer. Applications include gears for business machines and appliances, audio/video reels, rollers and cartridges, as well as hubs and wheels. (BF Goodrich Co., Specialty Polymers & Chemicals Division, Cleveland, Ohio, USA) (Source: Plastics World, August 1991)

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Economics and performance highlight new Ryton PPS grade

A glass-filled grade of Ryton polyphenylene sulphide (PPS) featuring reduced density is now available in developmental quantities.

Ryton PPS grade BR87 has a density of 1.22 grams per cubic centimetre. Tensile strength, rated at 10,000 psi, is higher than phenolic. The company claims that Ryton PPS BR87 has a strong price/performance ratio, making it highly competitive with phenolics and other thermosets. It also favourably compares with the Ryton PPS R-7 grade, a long-time favourite of applicance parts manufacturers. When fully commercial, BR87 is expected to cost 20 per cent less than R-7.

In addition to appliances, the company expects BT87 to be used soon in electronics and automotive components. (Phillips 66 Company, 776 Adams Building, Bartlesville, Oklahoma 74004, USA. Tel.: +1 918 661 6921. Fax: +1 918 661 1547) (Source: New Materials World, August 1991)

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Glossy grade of Aspect TPPE launched with excellent stiffness

Phillips 66 Company has announced that its Aspect A055 thermoplastic polyester (TPPE) is now available in commercial quantities. It is a 55 per cent glass-reinforced grade, with a proprietary formulation that provides excellent stiffness, thermal resistance and a glossy finish.

Aspect A055 provides tensile strength of 22.0 Ksi and flexural strength of 37.0 Ksi, giving it high strength and stiffness. This engineering resin has a heat deflection temperature of 230°C at 264 psi, a melting point of 253°C, and, according to the company, melts and flows easily during processing.

Available in select colours, Aspect TPPE combines polyethylene terephthalate with the proprietary additives to produce compounds having excellent strength, heat resistance and ease of processing. This system of engineering thermoplastics, available in 30 per cent and 45 per cent glass-reinforced grades, is available with flame-retardant properties and is suitable for use in industrial, automotive, electronic and small appliance applications. (Phillips 66 Company, 776 Adams Building, Bartlesville, Oklahoma 74004, USA. Tel.: +1 918 661 6921. Fax: +1 918 661 1547) (Source: New Materials World, August 1991)

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New thermoplastic for exterior auto-part applications

Along with the use of "traditional" plastic panels and trim, Isuzu Motors Ltd., 8 Tsuchidana, Fujisawa-shi, Kanagawa, Japan is using elastomer (an ether-ester block copolymer, or EEBC, reinforced with special fillers) for its front and rear bumper fascias. This is a departure from the use of polyurethanes in this application by the majority of automakers. The ether-ester compound provides better toughness and has a modulus of elasticity that is less dependent on temperature than polyurethanes. The material can be tailored to meet the wide range of fascia performance requirements.

Compared with polyurethanes, EEBC has a lower deflection under flexural load at 130°C (265°F), higher hardness and impact strength, lower tensile yield strength and elongation, and a lower flexural modulus at room temperature and at -30°C (-20°F).

Isuzu requires that bumper fascias have good performance at temperatures between -30°C and 60°C (-20° and 140°F). The fascia's impact resistance is critical at low temperatures. Fracture can be promoted by a rapid increase in resin modulus of elasticity at low temperatures, a characteristic of plastics that results in a sharp increase in stress due to material deflection when it is subjected to an impact force. In addition, certain fillers added to reduce the modulus of the resin can function as fracture-initiation points at low temperatures. These potential problems are overcome by tailoring the amounts of EEBC constituents (original material consisted of hard, or type A, and soft, or type B, constituents, while the modified material contains an additional soft, or type C, constituent) to decrease the flexural modulus of elasticity at the lower end of the temperature range, and by optimizing filler dispersion (via controlled compounding and mixing) to increase both impact strength and tensile elongation.

An oxidation stabilizer also must be added to the resin during compounding to prevent the thermal decomposition of polyester in the polycondensation reaction that occurs during mixing and moulding, and to prevent the deterioration of material properties. Selection of the proper stabilizer is critical because certain ones, such as the hindered phenol-base stabilizer present in the bumper material, can cause yellowing of the paint. Isuzu's stabilizer has a minimal discoloring effect and maximizes property retention. Note that a blocked isocyanate in the paint or the presence of copper ions in the paint facility also can cause discoloration. (Excerpt from Advanced Materials and Processes, August 1991)

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New family of materials

On 1 June 1991, Akzo and Alcoa formed a joint venture to produce and market materials for aerospace applications world-wide.

Arall and Glare are made up of alternating plies of thin aluminium alloy sheets and fibre reinforced epoxy prepreg. The epoxy acts as an adhesive, bonding the alloy sheets together. The laminates were developed to combine the higher specific strength and fatigue performance of advanced composites with the durability, supportability and ease of fabrication associated with aluminium.

The concept was developed in the 1970s by Delft University in conjunction with Fokker Aircraft. Their principal aim was to improve the fatigue resistance of aluminium alloy by using fibres to resist and control fatigue cracking.

Tests showed that Arall did improve fatigue resistance, particularly under high frequency cyclical tension-dominated loadings. This makes the material particularly suitable for wing applications. However, it was found that for low frequency fatigue loadings, such as those found in fuselage applications, aramid-based Arall could not be used because of potential fibre failure in the wake of a fatigue crack.

To overcome this problem, Akzo developed a second generation of aluminium composite laminates based on high-strength glass fibres. Called Glare, they were patented in 1987 and are just becoming commercially available. The better fibre/epoxy adhesion and the higher compressive strength of glass compared to aramid ensure that Glare is not prone to the fibre failure mechanism found in Arall.

Glare also exhibits better fatigue performance than both aluminium and Arall in riveted lap joints. In tests carried out on Glare, the aluminium rivets failed before the laminate. The results showed that the fatigue life of the riveted Glare lap joint was five times longer than Arall and 200 times longer than Aluminium 2024-T3.

The excellent fatigue resistance of Arall and Glare results from the crack closure mechanism exerted by the fibres on any fatigue crack in the aluminium sheets. Fibres bridging a fatigue crack lower the stress concentration at the crack tip, thus slowing or stopping crack growth.

The ability to stop growth is increased if a permanent stretch is introduced into the laminates during curing. If this is not done, the residual stress places the metal in tension and the fibres in compression. By giving the laminates a permanent stretch, this situation is reversed and high-strength aramid or glass fibres are placed in tension.

When placed under constant cyclic loading, Arall laminates with a 0.5 per cent stretch have been found to have their fatigue life increased by a factor of the order of 100 or 1,000 compared to 7075-T6 aluminium alloy sheet. If the laminate is not stretched during curing, then the corresponding factor is of the order of 10. Another significant advantage of the Arall and Glare laminates compared to monolithic aluminium is their lower density, which results from the inclusion of lightweight composites. The reduction depends on the number of layers: the density of the simplest 2/1 Arall laminate (two alloy sheets surrounding one layer of composite) is around 13 per cent less than monolithic alloy; the corresponding figure for a 5/4 Arall laminate is 18 per cent. The maximum saving attainable is approximately 20 per cent.

The moduli of both Glare and Arall are lower than for the alloys, making the aluminium/composite laminates less attractive for stiffness dominated structures.

An important advantage of Glare over Arall is its higher ultimate strain, although this is still lower than for the monolithic alloys. A higher ultimate strain means improved formability, and it also contributes to Glare's excellent blunt notch and sharp notch properties.

Glare also has a very high residual strength, so much so that the strength of Glare with a sawcut is higher than the tensile strength of aluminium. This makes Glare a very damage-tolerant material compared to both Arall and aluminium.

In many ways Glare and Arall can be handled in the same way as monolithic aluminium. They can be cold formed with radii only slightly greater than those obtainable with high-strength aluminium alloys: the minimum bend radius ranges from 2 mm for 2/1 Glare 2 and Arall 2 up to 8 mm for 4/3 Glare 1 and Arall 1. Furthermore, the laminates can be cut, drilled, joined and inspected using traditional methods.

The impact resistance of Arall and Glare has been found to be better than for fibre reinforced plastics. A particular advantage is that internal delamination will only occur in the metal/composite laminates after the surface has been dented, a factor which allows simple visual inspection. On the other hand, fibre reinforced plastics can delaminate without showing external damage, necessitating the use of non-destructive testing techniques such as ultrasonic inspection.

Arall and Glare offer a particularly good compromise in terms of durability. Corrosion is limited to the outer aluminium sheet and therefore has little effect on the overall mechanical properties. From the composites' point of view, moisture absorption is very low because they are only exposed at the edges and these are relatively straightforward to seal.

Further benefits of Arall and Glare include: lightning strike protection, with the outer aluminium layer providing electrical conductivity; improved sound damping - three times better than monolithic aluminium; and greater burn-through protection because the composite layers provide fire retardation.

Akzo estimates that Glare costs between seven and ten times as much as monolithic aluminium alloys. It argues that this is still at least 50 per cent less than the cost of advanced composites, and that it is competitive considering the weight savings available. These are claimed to be in the region of 20 to 30 per cent as a result of the lower density, higher strength and greater fatigue resistance of the laminates. When using Arall or Glare, the critical design criteria typically switches from fatigue to one of the following: blunt notch static strength, bearing strength, compression strength or transverse properties.

Glare is being promoted for fuselage applications requring a high damage tolerance. Both Arall and Glare are being put forward as alternative materials for wing construction, with the choice between the two depending on static loading requirements. Akzo estimates that aircraft applications of metal/composite laminates will be split approximately 70:30 between Glare and Arall respectively.

Particular components highlighted by Akzo for potential fabrication in Glare include fuselage skins, longerons, reinforcements and frames as well as tailplanes, ailerons, wings and stringers. The company estimates that 20 to 30 per cent of the primary structure of the next generation of aircraft could be made using the laminate. Other variants of Arall and Glare are also being developed by Akzo specifically for lightweight vehicle armour (called Protack) and for industrial applications (Fortamet). (Extracted from Engineering, June 1991)

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Bring in the reinforcements

One of the ways of reducing the cost of composite manufacture is by streamlining the assembly operations. In the case of reinforcements, this involves the tailoring of fabric structures for the manufacture of complex shapes, thus facilitating the use of automated composite manufacturing processes.

Until recently, most composite reinforcements were only available in the form of flat, two-dimensional fabrics. In the case of the warp and weft knits, reinforcing fibres can be inserted into the knitted structure to produce the increasingly popular fabrics knows as stitch bands.

It is from these basic structures that textile scientists and engineers have developed three-dimensional (3D) structures. They are essentially now less of a fabric and more of an engineered dry fibre composite structure in their own right.

3D fabrics comprise multiple layers of warp and weft yarns, interconnected with a system of through-the-thickness yarns.

There are two basic types of 3D fabrics:

- Cylindrical weaves, with fibres oriented in the radial, circumferential and axial direction. This type of weave is used to form cylinders and other thin or thick-walled bodies of revolution; and

- Orthogonal weaves, with fibres oriented in the X, Y and Z directions.

From these two basic types, a whole range of three-dimensional woven products can be produced, from structural preforms for wing box components, fuselage structures and turbine blades to rocket motor bodies. Commercial applications will also follow, especially in tandem with the automation of processes such as resin transfer moulding (RTM).

One of the major benefits of a 3D composite is the improved interlaminal shear strength, but the other major gain is a considerable increase in damage tolerance.

Advances are being achieved in braiding, knitting and weaving of 3D fabrics and shapes. Conventional braiding consists of interweaving two or more fibres to cross one another in a diagonal formation. Hence fibres are oriented at angles +0° and -0° to the longitudinal direction. Products produced by this process are tubular or circular in structure. Composites produced from braids have good shear resistance and torsional rigidity.

At the moment, the main disadvantages of 3D braided shapes are cost and size limitations. Even to produce a relatively small component, a large machine is required. In addition, the speed of production is slow. Hence components produced by the process are expensive. Automation and computer-aided design should bring down the cost of components.

Mechanically, composites produced from knitted shapes using glass fibres have properties equal to sheet moulding compounds. This is the major limitation of the process because of the reduction in properties due to the severe fibre bending. Their outstanding advantage, though, is the ability to conform and be stretched to follow complex shapes and deep draws.

Of all the processes described so far, weaving is probably the most versatile and widely known composite reinforcement production process. Yet it is the least understood in terms of the wide variety of reinforcement forms that it is capable of producing.

The ultimate step in composite reinforcement structures is the near-net shape weaving of a component. This is now a reality. In shape weaving, not only is it possible to weave the actual "shape" of the component, but also to tailor the width and multi-layer cross-sectional thickness as well as fibre volumes and orientations.

Major benefits of near-net shape 3D fabrics preforms include improved mechanical and impact properties. But by far the largest advantage of woven 3D shapes lies in the major advance that they represent for automating composite production processes such as resin transfer moulding. A dry fabric preform can simply be dropped into the mould prior to resin injection.

While near-net shape fabric preforms offer numerous benefits, they do have problems too. Cost is one, for low volume parts, because set-up costs are high.

These need to be reduced and productivity increased, which will involve greater use of computer-aided design and manufacturing. (Extracted from Engineering, January 1990)

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US reinforced plastics market levels off

The US market for reinforced plastics is flattening out according to the US Society of the Plastics Industry's Composites Institute. The figures, which include all reinforced plastics and not just advanced composites, show an increase of just 1.3 per cent last year and are expected to remain static this year.

Total sales in 1990 amounted to 1.17 million tons and are expected to remain unchanged this year. Falls in the construction, consumer and marine markets (3.3, 0.3 and 1.0 per cent respectively) will be offset by increases in the aerospace, business equipment, transportation, and corrosion- resistant equipment sectors (5.6, 0.4, 1.2 and 2.3 per cent respectively), according to the SPI.

The wider application of reinforced plastics in the automotive market led to a 4.1 per cent increase in the sector last year, despite weak car sales figures. This trend is expected to continue with the adoption of an SMC tailgate and roof for the 1992 GM Saturn estate car. The 1994 restyled Camaro and Firebird will also feature composite panels. (Source: Engineering, June 1991)

5. PUBLICATIONS

Hall of Famers named

The Plastics Academy is posthumously inducting five plastics pioneers into the Hall of Fame. They are: Fred Conley, Society of Plastics Engineers founder; Wilbert Gore, PTFE developer; John Grebe, developer of polystyrene, styrofoam and saran plastics; Prescott Huidekoper, first SPI president; and Spencer Palmer, a pioneer in US injection moulding. (Source: Chemical Marketing Reporter, 25 June 1990.)

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Interfacial phenomena in composite materials 1989: proceedings of an international conference
Edited by F.R. Jones, Boston: Butterworth, 1989, 323 pp. 620. 1'1892 IA4 18.9 89-15800
ISBN 0-408-04875-1.

Assessment of fibre-matrix adhesion. Interfaces in carbon fibre composites. Interfaces in polymer matrix composites: environmental aspects. Interfaces in polymer matrix composites: glass reinforcements - wetting. Metal matrix composites: interfacial reactions. Ceramic matrix composites.

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Plastic compounds

This four-page application guide concentrates on development of proprietary components using high performance fluoropolymer compounds. The 13 applications include wear-resistant piston rings, mould-bonded bearings, a thermoformable and heat-fusible polyetherimide thin film for foil film capacitors, a polyimide for air tool vanes and expansion support bearing. (Advanced Polymers Div., Furon Co., 386 Metacom Avenue, Bristol, Rhode Island 02809, USA.)

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Metal-polymer composites
NY: Van Nos Reinhold, 1990, Delmonte, John
250 pp. 620. 1'18 IA481 89-30815
ISBN 0-442-22100-2.

Contents: Production of finely divided metals and polymers. Moulding and casting of metal/polymer composites. Electroconductive polymer/metal composites. Plastics coated metals and metal coated plastics. Metal polymer structural composities. Radiation shielding by metal/polymer composites. Metal/polymer composities in magnetic components. Micro and nano electronic applications. Index.

Note: Intends to be a comprehensive and up to date guide to advances in metal/polymer chemistry and a survey of composite technology. Covers the applications of metal/polymer composites in the aerospace, automotive, aircraft, and electronics industry. Chapter references lead to the original sources. For materials scientists, developers of polymer materials, manufacturers of composites, adhesives and coatings and students.

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Plastics engineering handbook of the Society of the Plastics Industry
Michael L. Berins (Ed.). Van Nostrand Reinhold, 1990. 928 pp.

Updated fifth edition covers the chemistry and properties of plastics, processes and machines for converting plastics into products, handling and finishing, and design and testing. Included are 430 drawings and 250 photographs.

Order from: Van Nostrand Reinhold, 115 Fifth Avenue, New York, NY 10003, USA. Tel.: 800/926-2665; Fax: 606/525-7778.

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International directory of advanced inorganic composities 1991/1992

The International directory of advanced inorganic composites 1991/1992 is a new directory which gives detailed information concerning the world-wide advanced inorganic composites industry. Published by Materials Technology Publications, in association with Mitchell Market Reports, it covers the three main advanced inorganic composite types - ceramic composites, metal matrix composites and carbon/carbon composites.

Over 400 manufacturers and suppliers of composites are listed in the International directory of advanced inorganic composites 1991/1992, together with details of over 100 universities and research centres carrying out advanced inorganic composites research.

A detailed cross-reference listing of manufacturers and suppliers of advanced inorganic composites by composite type features four sections, covering ceramic matrix composites (without fibres or whiskers); ceramic matrix composites (with fibres or whiskers); metal matrix composites; carbon/carbon and other advanced composites. There is also a cross-reference listing of manufacturers and suppliers of advanced inorganic composites by end-product application.

A world-wide A-Z listing of universities and research centres provides details of advanced inorganic composite research projects being undertaken at each establishment. Full address details, together with telephone, facsimile, and telex numbers are provided.

For more information, contact the Marketing Department, Materials Technology Publications, 40 Sotheron Road, Watford, Herts., England WD1 2QA. Tel.: (0923) 37910; Fax: (0923) 211510.

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Ceramic materials for advanced heat engines
D.C. Larsen et al., Park Ridge, New Jersey, 1985, 330 pp. (English).

Ceramic applications in turbine engines
H.E. Helms et al., Park Ridge, New Jersey, 1986, 262 pp. (English).

High temperature polymer matrix composites
T.T. Serafini, Park Ridge, New Jersey, 1987, 412 pp. (English).

The three volumes contain contributions which have developed in the course of works of the

US Department of Energy and compile the latest knowledge respectively. The volume Ceramic materials for advanced heat engines is divided into two parts: a technical survey (specially oriented by SiC and Si_3N_4) and an economic contemplation. Two scenes of the further development are set up in the latter: in the first the supremacy of the USA on the market is presupposed, in the other one the Japanese are in this position.

In the volume Ceramic applications in turbine engines, the authors deal with the CATE-programme, which had aimed at the use of ceramic parts in turbine engines, and report in full detail about the tests concerning the selection of materials, the construction and production of ceramic parts as well as the testing. In the project, the limit of application was put to 1,050°C.

The volume High temperature polymer matrix composites gives an account of a fast-growing field of which the application temperatures are situated in the lower range of about 125°C, but in which inorganic components (graphite fibres) are used. In this respect it is a border area for both disciplines and quite appropriate that scientists for inorganic chemistry work in this field.

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Speciality materials catalogue

This 16-page reference catalogue lists chemicals, speciality chemicals, and industrial plastics manufactured by the company. Solvents, esters, plasticizers, glycols, acids and inorganic chemicals, thermoplastic resins, speciality polymers, adhesives and many other products are shown with data on physical properties and recommended uses. Catalogue also features colour photographs of typical products and general reference data on materials.

(Ashland Chemical Co., 5200 Paul G. Blazer Memorial Highway, Dublin, Ohio 43017, USA.)

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Advanced materials

An R&D handbook, listing government support, academic involvement, design possibilities, patenting information and organizations with a special interest in R&D in ceramics, polymers and metals, is available, priced £75, from the R&D Clearing House, 75 Whitechapel Road, London E1 1DU, UK.

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Thermoplastic powders

Data guide gives detailed technical information on thermoplastic powder prepegs and commingled yarn products. Sections include an overview of thermoplastic powder prepeg developments, thermoplastic polymer advantages, and selection factors. Specifications are provided on all performance and physical characteristics. (BASF Structural Materials Inc., 13504-A S. Point Blvd., Charlotte, North Carolina 28217, USA.)

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Specialized plastic parts

Design and engineering possibilities for custom moulded plastic parts and assemblies are explained in this 12-page colour brochure. Discussion explores company's expertise and facilities, then covers typical products, production methods, direct forming, casting to size, injection moulding and other operations. Many components are shown in typical industrial applications. (Polymer Corp., Box 422, Reading, Pennsylvania 19603, USA.)

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Advanced composites tooling

Set of two brochures details tooling for carbon and glass-fibre fabrics. First brochure introduces an epoxy staged-resin system impregnated into carbon or glass-fibre fabrics to the fabrication of composite tools. Data tables provide a complete description of prepregs and cured laminate properties. Similar data on second sheet highlights a bismaleimide formulation. Both pieces outline process requirements, performance requirements, and handling procedures. (BASF Structural Materials Inc., Narmco, 1440 N. Kraemer Blvd., Anaheim, California 92806, USA.)

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Handbook of fibre science and technology: Vol. III

High technology fibres Part B, edited by Menachem Lewin, Jack Preston (Marcel Dekker, Inc., 270 Madison Avenue, New York, NY 10016, USA), 1989, pp. XX + 332 pp.

This is the ninth publication in the Fibre Science & Technology series edited by Menachem Lewin of Israel Fiber Institute and Hebrew University, Jerusalem, Israel with an impressive Editorial Board of acknowledged fibre technologists from the United Kingdom, United States, Japan and Romania.

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European advanced ceramics directory

Containing 400 company entries and 100 research centre entries, the European Advanced Ceramics Directory has been published by Materials Technology Publications, 40 Sotheron Road, Watford, Herts., WD1 2QA, UK. Tel.: (0923) 37910.

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Handbook of plastic materials and technology

Edited by I.I. Rubin, Robinson Plastics Corp., USA.

This complete, single-source reference offers in-depth, up-to-date coverage of materials, processing, industry practices, assembly, technology and decorating in a format that is easily read and accessed. Prominent industry professionals answer questions regarding 119 different plastic topics - each in its own separate section - and useful auxiliary information, comprehensive tables, and handy appendices are included as well. 0471096342, 1,772 pp., 1990.

Internal stresses, dimensional instabilities and molecular orientations in plastics

L.C.E. Struik, TNO Centre for Polymeric Materials, The Netherlands.

Presents the results of an investigation conducted at the former Central Laboratory TNO between 1968 and 1973. Experimental verification of theoretical relationships is discussed in terms of model experiments. Whilst the topics of stress relaxation, the glass transition, creep, the WLF equation and mechanical spectroscopy are covered in all textbooks of polymer physics to some extent, there is no other single volume which attempts to cover this ground in a coherent and comprehensive manner. 0471926426, 472 pp., 1990.

Both books are published by: John Wiley & Sons Ltd., Baffins Lane, Chichester, West Sussex PO19 1UD, UK.

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Handbook of plastic materials and technology
Edited by Irvin I. Rubin, NY: Wiley, 1990. 1,745 pp. 668.4 TP1130 89-48281
ISBN 0-471-09634-2.

Includes 81 material sections and 38 processing sections written by authorities in their respective fields.

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High-performance plastics

High performance plastic parts for critical applications contains four pages of reference data on plastic-performance characteristics. Chart shows polyimides, metals, PTFE, liquid-crystal polymer, polyamide-imide, and other materials with listings of strength, heat deflection, wear and other properties. Guide includes reference notes for further study. (Mack Plastics Corp., 66 Tupelo St., Bristol, Rhode Island 02809, USA.)

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Successful composite techniques
K. Noakes. London: Osprey published 1989. Pp. vii + 128, £12.95, ISBN 0 85045 877 3.

This book is described as a practical introduction to the use of modern composite materials, i.e., composites consisting of thermosetting resins in conjunction with man-made fibres such as glass, carbon and aramid. It is very much a practical book, extremely well-illustrated with photographs and diagrams, aiming to enable the reader to become accomplished quickly in a limited number of aspects of manufacturing and simple, rudimentary design.

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Engineering plastics and composites, 728 pp. ASM International, Materials Park, Ohio 44073, USA.

The book provides names and addresses of manufacturers of resins, moulding compounds, fibres, fabrics, filters, laminates and related additives and bonding agents. Complete lists of trade names and generic designations are included.

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Corrosion of high-performance structural ceramics

Printed in Russian, this text was prepared by V. A. Lavrenko and Yr. G. Gogotsi. Chapters deal with high-temperature gas corrosion, corrosion in liquid media, effects of corrosion on physico-mechanical properties of ceramics, environmental effects on mechanical tests, and corrosion protection and development of corrosion-resistant ceramics. 1989, ISBN 5-229-00343-X. Metallurgiya Publishers, 2-nd Obydensky per. 14, 119857 Moscow, Russian Federation.

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Structural ceramics: fabrication, properties, application

Yu. G. Gogotsi prepared this report that discusses the general situation with structural ceramics in the world and in the USSR. Materials based on silicon carbine, silicon nitride, alumina, and zirconia are covered. Written in Russian, it contains nine illustrations, seven tables and 29 references. 1990, 19 pp. Znaniye Publishers, 57/3 Krasnoarmeyskaya ul., 252005 Kiev, Russian Federation.

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Fibre reinforced ceramic composites - materials, processing and technology
K. S. Mazdiyasni (ed.). Park Ridge (USA) 1990, 515 pp. bound (English).

Ceramic composites cannot be said to be very new. However, fibre reinforcement has come about only approximately ten years ago on a larger scale. This book deals for the first time with all the experience gathered in the field of ceramic endless and short fibres or whiskers, respectively, for ceramic composite materials. Special mention is given to the chemistry of the oxides, produced by means of the sol-gel process, and the non-oxide fibres, respectively, which have emerged from the ceramic polymers. The importance of fibre/matrix boundary layers and the long service life of the fibres in the matrix is pointed out especially. Twenty-nine internationally-known authors have cooperated in the compilation of the book. It can very well be used as reference material for the actual state of knowledge by all those - whether for studies or professional purposes - who deal with this group of materials, which will certainly be expanding enormously in the near future.

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High temperature materials handbook, volume 90

Provides 52 pages of revised data on types of materials usable to 4,000°F. Sections focus on machinable ceramics, tapes, ceramic fibres, conductive materials, ceramic cloths, adhesives, and epoxies. Listings review thermal and physical characteristics, chemical properties, and many applications. Selection chart, machining instructions, and casting guidelines are included. Cotronics Corp., 3379 Shore Parkway, Brooklyn, NY 11235, USA.

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National directory of recycling information

Sponsored by British Steel Tinplate and produced in association with the Townswomen's Guild. Published by The Industry Council for Packaging and the Environment, Premier House, 10 Greycoat Place, London SW1P 1SB.
ISBN 0 7199 1274 1.

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Understanding materials

An eight-page, full colour product catalogue available from Materials Information, a joint service of ASM International and the Institute of Metals. The 1991 catalogue offers metallurgists, materials scientists, librarians and others a spectrum of information products and services, ranging from technical and business abstracts journals to industry reports and online search aids. (The Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB, England. Tel.: (071) 839 4071; Telex: 8814813; Fax: (071) 839 2289.)

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The phosphating of metals
W. Rausch, 1990, Stevenage, Herts., Finishing Publications, casebound, 418 pp.,
ISBN 0 90447 711 8.

This second edition of a notable German book (originally published in 1988) has been excellently translated into English by Anselm Kuhn. Its chapters cover the range of topics that would be anticipated in a major work on this type of surface treatment. These are history, phosphoric acid pickling, phosphating processes, technical applications of phosphating, phosphating plant, effluent treatment, quality and process control, and standards.

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Advanced inorganics for electronic substrates and packages
Published in July 1991; 190 pp.,
ISBN 0 948696 12 5.

Contents:

Executive summary and Conclusions

Introduction: History and developments in electronic devices 1940 to 1960 and 1960 to date - developments in materials and processing - future developments - projects and initiatives.

Markets: Substrates and packages - hybrids - multilayer ceramic packages - powders.

Production and technology: Material properties - quality assurance including metallographic techniques - powder production - sintering - tape production for multilayer ceramic packages - metallization - thick and thin film techniques - circuit deposition techniques - lithographic techniques - component production.

Applications: Current status - substrates - packages including CERDIPs, grid arrays and chip carriers - hybrids - nanocomposites - superconductors.

The different materials - properties, production, consumption, markets and applications: Alumina - aluminium nitride - beryllia - boron nitride - diamond - glasses and glass ceramics - mullite and cordierite - other alumino-silicates - silicon carbide and other silicon ceramics - titanates - metals - silicon - other materials.

Activities of the various companies: In North America - Europe - Japan - the Russian Federation and other countries. (Mitchell Market Reports, P.O. Box 23, Monmouth, Gwent NP5 4YG, UK. Tel.: (0600) 772 721; Fax: (0600) 772 588; Telex: 297761.)

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High temperature superconductivity (Graduate texts in contemporary physics)
Edited by Jeffrey W. Lynn. Springer Verlag, 44 Hartz Way, Secaucas, New Jersey 07094, USA. 1990. xiv + 403 pp. ISBN 0-387-96770-2.

This book, offering material collected and assembled during 1987-1989 on the subject of high-temperature superconductors, is useful as an introduction to those starting serious research in the field. The authors have done a creditable job of presenting the important aspects of the field and illuminating some of the most important issues.

Notable chapters are those on Type II superconductors, for its unifying clarity and references to the subject of disordered materials; on the Josephson effect; on thermal and transport properties, for its general introduction and clear statement of the implications of transport and specific heat data on Hubbard insulator, Fermi liquid, and BCS models; magnetic properties, for the magnetic structure of Cu moments in $YBa_2Cu_3O_x$ and La_2CuO_4; electron pairing, for its eminently readable classification and exposition of the BCS theory, Bose condensation, and pairing by excitons, plasmons, spin fluctuations and bipolarons.

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Proceedings of the metal and ceramic matrix composites: processing, modelling, and mechanical behaviour
Edited by Ram B. Bhagat, Allan H. Clauer, and Probhat Kumar. The Minerals, Metals, and Materials Society (TMS), 420 Commonwealth Drive, Warrendale, Pennsylvania 15086, USA. 1990. xvi + 666 pp. ISBN 0-87339-119-5.

This proceedings contains 60 peer-reviewed papers presented at the International Conference on Metal and Ceramic Matrix Composites: Processing, Modelling and Mechanical Behaviour, held on 19-22 February 1990. It is divided into seven sections: processing of metal matrix composites; processing of ceramic matrix composites; fracture and fatigue; process modelling and deformation processing; interface and high temperature performance; damping, tibology, and NDC; and emerging technologies and applications.

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Fibre-reinforced ceramic composites - materials, processing and technology
Edited by K.S. Mazdiyasni, Noyes Publications Corp., Mill Road at Grand Avenue, Park Ridge, New Jersey 07656, USA. 1990. xvii + 515 pp.
ISBN 0-8155-1233-3.

This book is a compilation of works written by 29 recognized authorities covering 15 different topics within the scope of fibre-reinforced ceramics.

The first two chapters deal with mechanical and micromechanical modelling of fibre-reinforced ceramics and provide an excellent overview. The next four articles are dedicated to the area of ceramic fibres and whiskers, providing information on fibres produced from organosilicon polymers, synthesis and properties of VLS SiC whiskers, oxide fibres from chemical ceramic processes, and the interrelationship of processing, microstructure, and properties of ceramic fibres. The last half of the book covers many different aspects of ceramic matrix composites, from mechanical evaluation of fibre-reinforced ceramics to the future needs and opportunities of ceramic composites. Also included in this section are articles describing specific types of composites, such as whisker-reinforced ceramic composites, glass- and glass-ceramic-matrix composites, fabrication of ceramic-matrix composites via CVD and CVI technology, and composites made utilizing both melt infiltration techniques and metal-organic precursors.

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Following are eight new publications by The American Ceramic Society:

The American Ceramic Society, Inc., Book Service Dept., 757 Brooksedge Plaza Drive, Westerville, Ohio 43081, USA. Fax: 614-899-6109. Tel.: 614-890-4700.

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Ceramic dielectrics: composition, processing and properties
Ceramic Transactions, Vol. 8. Hung C. Ling and Man F. Yan, eds. Copyright 1990, hardbound, 425 pages. ISBN 0-944904-22-X. Order: TRANS8.

The papers contained in this volume were presented at the Symposium on Ceramic Dielectrics - Composition, Processing and Properties, held at The American Ceramic Society Annual Meeting, Indianapolis, Indiania, 1989. The Symposium was sponsored by the Electronics and Basic Science Divisions of the American Ceramic Society, and co-sponsored by the Electronics Division of the Japan Ceramic Society and organized by an international committee.

The objective of this symposium was to bring together international researchers from industry, universities and government laboratories who are investigating the compositions, processing, properties and applications of ceramic dielectrics. Ninety-two talks were presented at the symposium, including eight oral sessions with invited and contributed papers as well as a poster session. Principal topics in this symposium included compositional and processing studies of high dielectric constant ferroelectrics, temperature-stable and microwave dielectrics and piezoelectrics; processing of these materials via sol-gel or other chemical routes; structure and property relations of these dielectrics; and novel composite devices. Of particular interest has been an assessment of the use of relaxor ferroelectrics for capacitor application. The 38 papers in this volume represent a cross-section of the talks presented in the symposium. Thus, this book will provide a useful reference to the researchers in the field.

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Corrosion and corrosive degradation of ceramics
Ceramic Transactions, Vol. 10.
Richard E. Tressler and Michael McNallan, eds.
Copyright 1990, hardbound, 512 pages.
ISBN 0-944904-26-2. Order: TRAN10.

This volume constitutes the proceedings of an international symposium held as part of the First Ceramic Science and Technology Congress at Anaheim, California, on 1-2 November 1989.

This symposium attempted to cover all of the current research thrusts in this emerging field by inviting internationally-known authorities in the various subfields of this general topic. Major emphasis was placed on high-temperature corrosion behaviour in corrosive gasses and molten liquids largely because it is this regime of behaviour which often defines the safe use envelope in applications.

This collection of papers represents the state-of-the-art in our understanding of the corrosion and corrosive degradation of ceramics, and it is the first comprehensive book to review the whole field.

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Ceramic powder science III
Ceramic Transactions, Vol. 12. Gary L. Messing, Shin-ichi Hirano, and Hans Hausner, eds.
Copyright 1990, hardbound, 1,012 pp.
ISBN 0-944904-28-9. Order: TRAN12.

137 papers contributed from Australia, Brazil, Canada, China, England, Finland, France, India, Italy, Japan, Korea, Netherlands, Spain, Sweden, Switzerland, Taiwan, the United States, and Germany helped to make up the successful 3rd International Conference on Ceramic Powder Processing Science held on 4-6 February 1990, in San Diego, California, USA.

Topics covered include solution, vapour, and carothermal synthesis of ceramics powders; powder dispersion and rheology; forming densification; and electrical and mechanical property relations.

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Superconductivity and ceramic superconductors
Ceramic Transactions, Vol. 13. K. M. Nair and E. A. Giess, eds. Copyright 1990, hardbound, 792 pp. ISBN 0-944904-29-7. The American Ceramic Society Inc., Order TRAN13.

This volume contains a collection of papers concerning fundamental principles of superconductivity; phase relationships, crystal chemistry, and stoichiometry; new compositions, powder synthesis, and novel processing; sintering-microstructure-property relationships; thin and thick films; and device design concepts, fabrication methods and reliability. Presented at the First International Science and Technology Congress in Anaheim, California, 1989, all the papers published in Volume 13 were reviewed by experts in the area.

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Electro-optics and nonlinear optic materials
Ceramic Transactions, Vol. 14. K. M. Nair, A. S. Bhalla, and E. M. Vogel, eds.
Copyright 1990, hardbound, 320 pp.
ISBN 0-944904-32-7. Order: TRAN14.

These proceedings are from the First International Science and Technology Congress, Anaheim, California, 1989. The major topics of the symposium were nonlinear optical, acousto-optical, magneto-optical devices and applications; photosensitive materials and devices; and optical fibres and optical disks. Over 17 invited papers and many contributed papers were presented; all papers from the conference that are published here were reviewed by experts in the field.

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Materials and processes for micro-electronic systems
Ceramic Transactions, Vol. 15. K. M. Nair, R. Pohanka, and R. C. Buchanan, eds.
Copyright 1990, hardbound, 512 pp.
ISBN 0-944904-31-9. Order: TRAN15.

This volume contains a collection of papers presented at the First International Science and Technology Congress, Anaheim, California, 1989. These proceedings cover dielectric compositions; multilayer capacitor systems; glass ceramic composite materials and processing concepts; multilayer interconnect packages; thick and thin film hybrids and wafer scale integration; and device fabrications. Over 27 invited papers were presented during the three-day conference. All of the papers included in this volume were reviewed by experts in the area.

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Failure analysis of brittle materials
Advances in Ceramics, Vol. 28. V. D. Frechette. Copyright 1990, hardbound, 160 pp.
ISBN 0-944904-3-0. Order: ADVC28.

This important new book on fractography, written by a respected authority in the field, provides researchers, manufacturers, applications engineers, geologists, and forensic scientists with important fundamental tools for reading cracks and fractures.

Contents: Initiation and development of brittle failure; fundamental markings on crack surfaces; the pattern of forking; the seeds of failure; estimation of stress at failure; effects at inclusions; anisotropic materials; procedures and techniques; common conditions of failure; examples in practice, and the expert witness.

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Alumina Chemicals: Science and technology handbook
LeRoy David Hart, Editor. Copyright 1989, hardbound; 800 pp. ISBN 0-916094-33-2.
Order: ALUHBK.

This new handbook is an expansion and updating of Walter H. Gitzen's invaluable source book, Alumina as a ceramic material. The new volume is a comprehensive reference for in-depth information on the science and technology of a remarkable family of products known as alumina chemicals. These low-cost versatile materials are produced commercially in large quantities for use in a wide variety of end products which serve many of the daily needs of people throughout the world. Examples of these end products include: toothpaste, carpet backing, industrial ceramics, electronic substrates, antiperspirants, abrasives, refractories, insulators, flame retardants, synthetic marble, fine china, optical glass, ovenware, sorbents, desiccants, catalysts and polishing compounds.

A total of 57 world-renown scientists and engineers having expertise in the aluminas contributed 50 chapters to the book. These chapters, organized into seven sections, reflect the knowledge, experience and future expectations acquired by working with these materials. Many of the contributors have spent most of their lifetime developing a deep understanding of alumina chemicals. The insights they provide have added a special dimension to the information presented.

Subjects covered in the various chapters include fundamental properties of the basic alumina products, current commercial products and production processes, state-of-the-art assessments on a wide range of applications, industrial hygiene considerations, the long-range future of alumina chemicals and an extensive glossary. Each chapter is a "stand-alone" treatise complete with selected references pertaining to the specific subject being addressed. Liberal use has been made of visual aids in presenting the information.

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6. .AST EVENTS AND FUTURE MEETINGS

1991

25-27 November, Montpellier, France
2nd International Scientific Workshop on Biodegradable Polymers and Plastics (C. Braud, LSM, INSA Rouen, BP 08, F-76131 Mont-Saint-Aignan Cedex, France; Fax: 33-35-146566)

THE FOLLOWING WORKSHOPS ARE BEING PLANNED:

TIFAC/Department of Science and Technology, Prof. R. S. Ganapathy, Director, National Materials Policy Project, New Delhi 110 016, India. Fax: (91) 011 6863866.

11-12 November, New Delhi, India
Development of standards for advanced materials strategic issues (Bureau of Indian Standards & TIFAC)

9-10 December, Bangalore, India
Strategies for composites (TIFAC National Aeronautical Laboratory and ISAMPE)

11-13 December, Bangalore, India
International issues in materials Policy (UNIDO & TIFAC)

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3-5 December, San Jose, California, USA
2nd National Technology Transfer Conference and Exposition "The road to the future - technology 2001" (Technology Utilization Foundation, 41 E. 42nd Street, Suite 921, New York, NY 10017, USA)

10-11 December, London, UK
Metal Matrix Composities (Institute of Metals, 1 Carlton House Terrace, London SW1Y 5DB, UK. Fax: (071) 839 3576)

1992

Plastics show draws a crowd

Plastics USA, a new show/conference package focused to plastics equipment manufacturers as well as plastics producers, users and processors in the North, Central and South American marketplace, is not being held until October 1992, yet has already attracted 251 exhibitors. Sponsored by the Society of the Plastics Industry Inc. and Society of Plastics Engineers, the new show will only be held once every three years. (Source: Chemical Marketing Reporter, 12 September 1991)

18 January, Bombay, India
Finance and materials: Strategies to 2000 (TIFAC and Industrial Credit and Investment Corp. of India)

3-7 February, Perth, Australia
Greening the Polymer Industry, 19th Symposium (19APS Secr., c/o Chem. Centre (WA), 125 Hay St., East Perth WA 6004, Australia)

4-6 February, Essen, Germany
Materials in Micro-electronics (ELMAT-2) (MESAGO, Messe u. Kongress GmbH, Rotebühlstr. 83-85, W-7000 Stuttgart 1, Germany)

1992

19-21 February, Paris, France
TECH'MART 92. (GAMI, 3, rue Fernand Hainaut, 93407 St. Ouen Cedex, France. Fax: (1) 401 216)

9-12 March, Hong Kong
Interplas Asia, Plastics Exhibition (Cahners Exhibitions Ltd., 2808 Office, Tower, Convention Plaza, 11 Harbour Road, Wanchai, Hong Kong)

16-18 March, Bad Neuheim, Germany
SENSORS (VDI/VDE Gesellschaft Mess- und Automatisierungstechnik, Postfach 1139, W-4000 Düsseldorf, Germany)

22-27 March, Somerset, New Jersey, USA
Semiconductors and Superconductors (Society of Photo-Optical Instrumentation Engineers, Lennestr. 55, W-5300 Bonn, Germany)

31 March - 2 April, The Hague
UTECH '92 - Conference and processing seminars on:

- Elastomer technology
- Coatings, adhesives, sealants and encapsulants
- Flexible foam technology
- Rigid foam technology and
- Microcellular foam technology

(Crain Communications Ltd., Cowcross Court (2nd Floor), 75-77 Cowcross Street, London EC1M 6BP. Fax: +44(0)71 608 1173)

6-8 April, Bordeaux, France
The Fibre Society Meeting - first time in Europe with the support of: EACM (European Association for Composite Materials), Bordeaux and ITF (Institut Textile de France), Lyon (Dr. J. Skelton, Albany International Research Co., 777 West Street, P.O. Box 9114, Mansfield, Massachusetts 02048-9114, USA. Fax: 508-339 4996)

7-10 April, Bordeaux, France
5th European Conference on Composite Materials (EACM, 2 Place de la Bourse, 33076 Bordeaux Cedex, France. Fax: (33) 56 44 32 69)

8-10 April, Thessaloniki, Greece
3rd International Conference on Energy and Building in Mediterranean Area (Laboratory of Building and Construction Physics, Dept. of Civil Eng., Aristotle University of Thessaloniki, P.O. Box 429, 54006 Thessaloniki, Greece. Fax: (031) 200392)

1992

9-14 April Osaka, Japan	JP '92 - Plastics and Rubber Fair (JP Fair Association, Ginza Yamagishi Bldg., 2-10-6 Ginza, Tokyo 104, Japan)
14-16 April Como, Italy	Regularities, Classifications and Predictions of Advanced Materials (Nat. Res. Council Canada, M-55, Room 275, Ottawa, Canada K1A 0S2, Fax: 613-952-8246)
13-15 May Düsseldorf, Germany	The Recycling of Metals (ASM European Office, rue de l'Orme, 19 Olmstraat, B-1040 Brussels, Belgium. Fax: 32 2 733.43.84 - 734.67.02)
26-29 May Cleveland, Ohio, USA	Composite Interfaces ICCI-IV: 4th International Conference (Prof. Hatsuo Ishida, General Chairman, ICCI-IV, Dept. of Macromo Science, Case Western Reserve Univ., Cleveland, Ohio 44106, USA. Fax: 216/368-4164)
26-29 May Strasbourg, France	Electronic Materials (MRS Spring Meeting, Centre de Recherche Nucleaires, Lab., PHASE, Prof. P. Siffert, F-67037 Strasbourg Cedex, France. Fax: (88) 280 990)
4-6 June Modena, Italy	IMAT '92: International Fair of Innovative Materials. The exposition will feature raw materials, equipment, research, end products, and applications for advanced metals and alloys, intermetallics, engineering plastics, advanced technical ceramics, specialty glasses, and new carbons. The technical programme will include invited talks by recognized authorities from industry and research on topics such as policy for materials research, international markets, standardization, trends in research, etc. The official languages will be English, Italian, and Japanese, with simultaneous translation. Contact Conference Secretariat IMAT '92, Techna - P.O. Box 174, 48018 Faenza, Italy. Tel.: (+546) 22461 Fax: (+546) 664138.
22-24 June Paris, France	Workshop on Plastic Optical Fibres and Applications (IGI Europe, c/o AKM AG, P.O. Box 6, CH-4005 Basel, Switzerland. Fax: 41-61691-8189).

1992

22-25 June Orlando, Florida, USA	Conference on Composite Materials. The 6th Japan-United States Conference on Composite Materials. Further details are available from Ken Reifsnider, 120 Patton Hall, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061, USA. Fax: 703/231-4574.
23-27 June Hangzhou, China	1st Pacific RIM International Conference on Advanced Materials and Processing (PRICM-1) (Sponsoring the four-day conference are The Minerals, Metals & Materials Society (TMS), Chinese Society of Metals (CSM), Japan Institute of Metals (JIM) and Korean Institute of Metals (KIM)) (PRICM-1 Secretariat, Chinese Society of Metals, 46 Dongsixi Dajie, Beijing 100711, People's Rep. of China. Fax: 86-01-5124122)
12-15 August Gothenburg, Sweden	EASST MEETS 4S IN GOTHENBURG Annual Meeting of the Society for Social Studies of Science (4S) jointly with the European Association for the Study of Science and Technology (EASST). The 1992 conference has two preliminary themes: - "500 years after Columbus" - "Europe after 1992" (Center of Science Studies, Gothenburg University, S-412 98 Gothenburg, Sweden. Fax: +46-31-63 47 23)
7-11 September Berlin, Germany	Third International Conference on Low Cycle Fatigue and Elasto-Plastic Behaviour of Materials (Organized by Deutscher Verband für Materialforschung und -prüfung (DVM), held under the auspices of the Fed. of Europ. Materials Soc. (FMS) and co-sponsored by a number of international bodies including The Institute of Metals) (DVM-Office, Unter den Eichen 87, W-1000 Berlin 45, Germany. Fax: (030) 811 93 59)

<u>Previous issues</u>

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Issue No. 5	Composites
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