

**DESIGN  
DATA FOR  
REINFORCED  
PLASTICS**

A GUIDE FOR  
ENGINEERS  
AND DESIGNERS

**NEIL L. HANCOX AND  
RAYNER M. MAYER**

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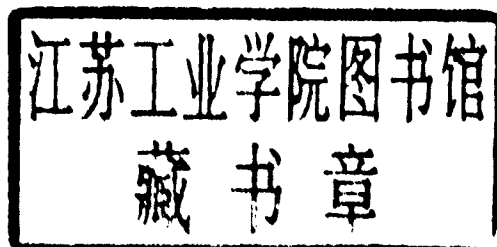
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# **DESIGN DATA FOR REINFORCED PLASTICS**

This book is dedicated to  
Margaret, Mark and Duncan  
and  
Pauline, David and Helen

# PREFACE

Fibre-reinforced plastics are a group of materials whose properties can only be determined after a component or structure has been fabricated. This poses both a challenge and an opportunity for those who would use these materials:

- a challenge because one has to surmise or assume a certain set of properties in order to undertake the design;
- an opportunity because it is possible to place the reinforcement so that it balances the imposed loads exactly.

This book addresses the challenge, because the data required for design are scattered far and wide and are not otherwise available in a form in which they can be used directly.

The assembled data are believed to be characteristic of the principal materials used for general purpose mechanical engineering. This book is neither a compendium nor a database and so where gaps appear it is either because the data do not exist, or the authors have been unable to locate them.

If this book is found to be useful, then we hope that others may be encouraged to fill the gaps in our knowledge or submit data, which could be used in subsequent editions.

Whilst the book is self-contained, the accompanying volume on design principles (Mayer, R.M. (ed.) (1993) *Design with Reinforced Plastics*, Design Council, London) may need to be consulted if readers are not acquainted with the design process.

If this book helps to encourage others to design with these materials, then the authors' labours will have been well rewarded.

Rayner Mayer  
Yateley  
and  
Neil Hancox  
Abingdon,  
June 1993.

# LAYOUT OF THE BOOK

The first three chapters discuss the primary design considerations, the material selection process for composites and the properties of the basic constituents. These chapters should enable the designer to establish a broad perspective of what might be possible when such constituents are incorporated to form a composite.

Data on short-term mechanical properties of composites are presented in the next three chapters. A clear distinction is made between random, fabric and aligned reinforcement and the properties that these produce.

A further four chapters consider properties associated with the performance of a composite under various conditions, including the effects of impact, fire, environmental conditions and long-term loading, either continuous or cyclic.

Each of the major manufacturing processes is briefly described, together with a listing of the relevant data location. Quality control of processing is discussed in the final chapter.

# HOW TO USE THIS BOOK

This book can be used in various ways:

For readers conversant with composites, key words or locators, placed in the margin, enable data to be located. The search may either be for a suitable material, or for a required property level.

If more basic information is required first, Chapter 2 should be consulted for the initial selection of constituents and Chapter 3 for specific properties of fibres and resins. Resin properties are amplified further in Chapter 4.

The classification of mechanical properties is by resin type in Chapter 4 and by fibre type in Chapter 5. This is consistent with the way in which the materials are used. The influence of processing on both material selection and properties is discussed in Chapter 11, and may restrict the choices set out in Chapters 4 and 5.

Chapters 6 to 10 describe other properties which need to be considered as part of the design process, whilst Chapter 12 outlines aspects of quality assurance to ensure compliance with the design.

If, as is often necessary, the design has to be iterated, then the material selection may need to be reconsidered, and the available data reviewed. Databases and manufacturers' information can be used to supplement what is set out here.

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# GLOSSARY

Note: This glossary is self-consistent with that proposed by the ASM International Handbook Committee as set out in Volume 2 of the Engineered Materials Handbook, published by ASM, Metals Park, Ohio, USA

ABS	Acrylonitrile butadiene styrene resin.
Accelerator	A material that, when mixed with a catalyst or resin, speeds up the curing process.
Additive	A substance added to the resin to polymerize it such as accelerator, initiator, or catalyst; or to improve resin properties such as filler or flame retardant.
AFNOR	Association Française de Normalisation.
Aramid fibre	Organic-based high performance fibre.
Aspect ratio	Ratio of fibre length to diameter.
ASTM	American Society for Testing and Materials.
ATH	Aluminium trihydrate.
Autoclave moulding	A process in which both heat and pressure is applied to a composite placed in an autoclave.
Barcol hardness	Micro-hardness indentation technique.
B-staging	Partial reaction of a thermosetting resin.
Binder	A compound applied to fibre mat or preforms to bond the fibres before moulding or laminating.
BMC	Bulk moulding compound (see compounds).
BPF	British Plastics Federation.
BS	British Standards.
BSI	British Standards Institute.
BVID	Barely visible impact damage.
CAA	Civil Aviation Authority, UK.
C-glass fibres	A glass used for its chemical stability in corrosive environments.
Catalyst	A material that when added in small quantities increases the rate of cure of a resin.
CEC	Commission of the European Community.
CEN	Comite Européen de Normalisation.
Centrifugal moulding	A process in which chopped fibres, impregnated with resin, are sprayed into the inside of a mould which is rotated to consolidate the mixture.
CFM	Continuous filament mat.

COM	Contact moulding fabrication process.
Compound	An intimate mixture of a resin with other ingredients such as catalysts, fillers, pigments and fibres – usually containing all ingredients necessary for the finished product.
Composite	A generic term to describe the mixture of a fibrous reinforcement and resin matrix.
Consolidation	A process by which the fibre/resin mixture is compressed by various processes such as a roller, vacuum or pressure to eliminate air bubbles and achieve desired properties.
Contact moulding	A process in which the composite is laid up on a mould either by hand or by spraying short length fibres impregnated with resin.
CRM	Continuous random mat.
CFRP	Carbon fibre-reinforced plastic.
CSM	Chopped strand mat.
Cure	The process of cross-linking a plastic material to produce a rigid, solid object.
Curing agents	Materials added to resins to make them cure.
D-glass fibres	Glass with good dielectric properties.
Delamination	Separation between two or more layers of a composite due either to incorrect processing or subsequent degradation during use.
Denier	A numbering system for yarns and filaments in which the yarn number is equal to the weight in grams of 9000 metres. The lower the denier, the finer the yarn.
DIN	Deutsches Institut für Normung.
DMC	Dough moulding compound (see compound).
Drape	The ability of a fabric to conform to a shape or surface.
E-glass fibre	Glass fibre in general use.
E-CR glass fibre	A type of E-glass fibre with enhanced chemical resistance to corrosion.
EFTA	European Free Trade Association.
EN	European standard.
Epoxy resin	A thermosetting resin widely used with high performance fibres.
FAA	Federal Aviation Authority, USA.
Fibre	A material in filamentary form having a small diameter compared with its length.
Fibre content	The amount of fibre present in a composite usually expressed as a percentage volume or weight fraction.

Filament	See fibre.
Filament winding	A process which involves winding fibres or tapes onto a mandrel – these are generally pre-impregnated with resin.
Filler	An inert material added to a resin to alter its properties or to lower cost or density – generally in the form of a fine powder.
Finish	Materials used to coat filament bundles – usually contains a coupling agent to improve the fibre to resin bond, a lubricant to prevent abrasion and a binder to preserve integrity of a filament bundle.
Finished items	Items made of fibre-reinforced plastic, which are fully cured – such items generally consist of standard sections such as rod, bar, tube, channel or plate and are usually available ex stock from suppliers.
Foam cores	A foamed resin created by using a foaming agent – rigid foams are useful as core materials in sandwich panels between stiffer outer layers.
FRP	Fibre-reinforced plastic.
$G_1, G_2, G_3$	Fracture energies.
Gel coat	The surface layer of a moulding used to improve surface appearance or properties – applied using a quick-setting resin.
Gel time	The time period from mixing of the curing agent with the resin until the mixture is sufficiently viscous that it does not readily flow.
Geometric efficiency	Measure of the directionality of the fibre reinforcement.
Glass transition temperature	Temperature at which significant changes occur in properties of cured resin due to enhanced molecular mobility.
GMT	Glass mat thermoplastic.
GRP	Glass-reinforced plastic.
Hardener	A substance added to a resin to promote curing.
HDT	Heat distortion temperature (Note: varies according to load applied during the test).
HM fibre	High modulus version of a fibre.
HS fibre	High strength version of a fibre.
Hybrid	A composite containing two (or more) types of reinforcement.
IEC	International Electro-technical Commission.
ILSS	Interlaminar shear stress.
IM	Injection moulding process.

IMC	Injection moulding compound (see compound).
Impregnation	The process of introducing resin into filament bundles or fabric laid up in a mould.
Initiator	A substance which provides a source of chemical agents to promote curing.
Injection	A process used for introducing a liquid resin (or heat softened thermoplastic) into a mould.
Injection moulding	A process which involves injecting a formulated moulding compound into a mould.
Interface	The area between the fibre and the matrix.
ISO	International Standards Organisation; International standard.
JIS	Japanese industrial standard.
Kevlar	A type of aramid fibre.
K	Stress intensity factor.
LEFM	Linear elastic fracture mechanics.
Mandrel	A form of mould (usually associated with a component having cylindrical symmetry).
Mat	A material consisting of randomly orientated fibre bundles which may be chopped or continuous, loosely held together with a binder or by needling.
Matrix	The resin in which the fibrous reinforcement is embedded.
Methacrylate	A thermosetting resin.
Mould	The tooling in which the composite is placed to give the correct shape to the article while the resin cures.
Moulding	An article manufactured in a mould.
Moulding compounds	A type of compound suitable for moulding (see compound).
Moulding process	The process by which an article is made in a mould.
NDE, NDT	Non-destructive evaluation, non-destructive testing.
Needled mat	A fabric which consists of short fibres felted together with a needle loom – a carrier may or may not be used.
NPG-polyester	A type of polyester resin formed using neopentyl glycol.
Oxygen index	A method for measuring flame spread.



PA	Polyamide resin (commonly known as nylon).
PAI	Polyamide imide resin.
PAS	Polyaryl sulphone resin.
PC	Polycarbonate resin.
PE	Polyethylene fibre or resin.
PEEK	Polyether ether ketone resin.
PEI	Polyether imide resin.
PEK	Polyether ketone resin.
PES	Polyether sulphone resin.
Phenolic	Thermosetting resin.
Polyimide	A thermoplastic or thermosetting resin with excellent high temperature properties also referred to as PI.
Ply	A single layer in a laminate.
Polyester	A thermosetting resin widely used with glass fibre.
PP	Polypropylene resin.
pph	Parts per hundred.
ppm	Parts per million.
PPM	Prepreg moulding.
PPO	Polyphenylene oxide resin.
PPS	Polyphenylene sulphide resin.
Preforming	A process by which fabric (or filaments) can be shaped into a desired form using a mould, before full impregnation – this is achieved by coating the reinforcement with a small amount of thermoplastic binder.
Prepreg	An intermediate fibre-reinforced plastic product which is ready for manufacture into a component – either in the form of sheet (for moulding) or tape (for winding).
Prepreg moulding	A process by which prepreg material is moulded either by autoclave or vacuum bag.
Press moulding	A process in which a press (cold or heated) is used to form an article from a compound comprising a mixture of fibres and resin.
PRM	Press moulding fabrication process.
PS	Polystyrene resin.
PSP	Polystyryl pyridine, a thermosetting resin with excellent high temperature properties.
PSU	Polysulphone resin.
PUL	Pultrusion fabrication process.
Pultrusion	A process in which filaments and/or fabric coated with resin are pulled through a heated die and rapidly cured to retain the die shape.
PVC	Polyvinyl chloride resin.
R-glass fibre	A high strength version of E-glass.
RIM	Reaction injection moulding process.
RRIM	Reinforced reaction injection moulding.