Materials **Composites**

Introduction

Composite materials are constructed from two or more elements to provide a material that has different properties to the individual elements. The constituent parts of a composite are the Matrix, the Reinforcement (Fibres) and sometimes a Core is included. There are numerous different manufacturing techniques for composites. These include hand lay-up, spray lay-up, pressure moulding and pultrusion.

Matrix

The matrix acts as the bulk material and transfers load between reinforcement. The matrix also has an additional role, which is to protect the reinforcement from the environment, abrasion and impact.

Reinforcement

The reinforcement provides the strength and stiffness properties of a composite. The form and arrangement of the fibres as they are introduced to the mould can vary significantly. They can be arranged as short strands of randomly orientated whiskers, a bundle of fibres, a unidirectional fabric, a woven fabric, a braid (tubular) fabric or a multi-axial fabric. Combinations of reinforcing materials can be utilised to provide a multitude of composite properties, where the material characteristics are aligned with the required performance properties.

The selection of the fibre arrangement depends on the loading condition requirements of the component and the constraint on the mass of the resulting component. For low specification composites, such as low cost glass fibre reinforced boats, the strength to weight ratio is not so critical, so a reinforcement for this composite would be of short whiskers that are randomly orientated, commonly referred to as “Chopped Strand Mat (CSM)”.

Core

Another important material that can be included as part of a composite material component is the Core, this is usually a low density material that is used to fill the gap between two Reinforcement/Matrix ‘skins’ or laminates, the resulting construction is often referred to as a Sandwich Structure.

Composite Types

There are three types of composite materials, Polymer Matrix Composites (PMC), Metal Matrix Composites (MMC) and Ceramic Matrix Composites (CMC).

The most widely used composites are PMCs. These are mainly used in ambient temperature applications. MMCs are commonly used to increase the strength of low-density metals, whilst using providing a material that maintains the metals toughness and manufacturing qualities. CMCs are used extensively in high temperature applications which require high strength and toughness characteristics.

Metal and ceramic matrix composites are relatively new technologies. This is evident when observing the extent of their application, as it is limited to high performance components and assemblies on advanced equipment.

Polymer Matrix Composites

Matrix

Common types of resin used to provide the composite matrix are Polyester, Vinyl ester and Epoxy.

Polymers are not recognised as the strongest of materials, but in the thermosetting resin form they provide excellent abilities to be moulded into complex shapes and to adhere strongly to the fibres. Accelerator and catalyst elements can be added to the resins in varying amounts to allow the polymerisation reaction to be controlled to provide varying material properties. Use of the catalyst element needs to be carefully controlled to ensure the reaction is not too rapid and to avoid insufficient curing.

Polyester resins are the most widely used, this is maybe due to the fact that they can be used to construct composites without the need to introduce pressure.

Vinyl ester resins are similar to polyesters but provide better resistance to chemical and water attack and also display improved toughness.

Epoxy resins exhibit higher levels of mechanical strength and they can also be more resilient to environmental attack.

Reinforcement

The reinforcing materials that are widely used for PMCs are glass, carbon, aramid and boron. They can be arranged as short strands of randomly orientated whiskers, a bundle of fibres, a unidirectional fabric, a woven fabric, a braid (tubular) fabric or a multi-axial fabric.

Carbon Fibre

Many different types of carbon fibre are available. The base materials used for producing the fibre are polyacrylonitrile, pitch or cellulose. Modifying the fibre production processes produces different classes of fibre, these are, high strength (standard modulus), intermediate modulus, high modulus, and ultra high modulus. A 'size' is applied to the surface of fibre to enable it to be handled in winding and fabric forming processes without incurring damage.

Glass Fibre

Glass fibres are produced in three main forms:

E-glass (electrical grade)	Most commonly used, low cost, low impact strength. Widely used in marine industry.
S-Glass (higher strength grade) [also known as R-glass & T-glass]	Higher tensile strength and modulus, relatively costly (£E-glass x 10). High cost restricts its use to aerospace and defence industries.
C-glass (chemical resistant grade)	Provides higher chemical resistance, used for outer layers of composites.

Aramid Fibre (Kevlar)

Aramid is a man-made organic fibre, which has a high tensile strength, a low compressive strength and provides high thermal insulation and fire resistance properties. This fibre also has a high resistance to shock loading and a low density, these two factors combined promote its use in bulletproof clothing.

Boron

Boron fibres used in PMCs are normally manufactured by coating the surface of carbon fibres with boron. This process adds even more expense to the carbon fibres and so the additional strength and stiffness achieved, limits its use to high specification aerospace and sports equipment applications.

Core Materials

The core element of the composite component acts as a medium for providing additional stiffness of a structure with very little mass penalty. The core is constructed from a low-density material and separates two or more composite 'skins' or laminates. If the composite component is loaded in bending as shown below, then the upper skin is supporting compression loads and the lower skin is supporting tension loads, this then loads the core in shear. This requires the core to be able to resist shear loading, provide sufficient stiffness and withstand compression from the skin deflection. The core materials that are commonly used are foam, honeycomb and occasionally low-density wood. Manufacturing requirements of the core is that they are easily formed into shape and that they are compatible with the matrix resin.

Foam

The most commonly used foam is PVC based and closed cell, it can be modified to provide a number of different performance characteristics, including improved toughness and fire resistance. This flexibility lends itself to use in a wide variety of applications. Other foams used do not perform as well across the range of properties, but they can be used for lower specification applications, these foams include Polystyrene and Polyurethane. However, the Polymethyl methacrylamide foams provide superior strength and stiffness properties, but their high cost restricts their use to high performance applications.

Honeycomb

Honeycomb cores can be manufactured from paper, plastics and low-density metals, such as aluminium. The manufacturing techniques vary significantly depending on the material properties, the wall thickness and cell size of the honeycomb material. Further issues concern the size of the bonding surface. If insufficient bond surface is available then the honeycomb cells can be filled with a suitable foam.

Wood

Low-density wood cores, usually balsa wood, are used with the wood grain perpendicular to the skin surface provide sufficient stiffness and additional properties of sound absorption and thermal insulation. Major considerations are concerned with reducing the quantity of resin absorbed by the wood and reducing the exposure of the wood to the environment to reduce the rate at which it degrades.

Metal Matrix Composites

This type of composite construction is used primarily to increase the strength of low-density metals such as aluminium alloys, copper, titanium alloys and magnesium alloys. Other rational for constructing MMCs is to increase the wear resistance and higher temperature performance. The matrix material can be reinforced with continuous fibres and wires or by short fibres, whiskers or particles.

The complex nature of these materials and their manufacture limits their use to high performance applications, in industries such as automotive, aerospace, and power.

Some of the commonly used reinforcing materials are Boron/Tungsten, Titanium, Alumina, Graphite and Silicon Carbide.

Ceramic Matrix Composites

CMCs are highly advanced materials and their use is restricted to applications where high strength or high toughness is required at high temperatures. The high cost of producing CMCs has restricted their use to applications in the power generation and aerospace applications.

Silicon Carbide and Boron Nitride and other ceramic fibres are used to reinforce ceramics matrices, such as Aluminium Oxide and Silicon Carbide.

Internet Resources

The Composites Processing Association is a UK-based organisation that actively promotes the increased use of composites in a wide ranging number of applications and market sectors.

The NetComposites website is an online resource for 'Knowledge in Composites' and is a body that advances the use of composites. The 'Guide to Composites' section provides a useful introduction to composite materials, applications and construction.

The Nottingham University Composites Club actively promotes the technical advancement and application of composite materials. This is achieved through seminars, case studies, site visits and demonstrations.

The Advanced Composites Manufacturing Centre (ACMC) at the University of Plymouth provides training and technical support through applied engineering research and development of Polymer Matrix Composites.