MECHANICAL PROPERTIES OF POLYMER COMPOSITE MATERIALS

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Abstract

In this paper, composite materials and its properties are discussed in detail. It is also discussed their importance and replacement for metals because of their properties like low weight, corrosion resistance etc. Now-a-days, there is a great importance of usage of these materials in various applications in all Engg. Fields. The paper also brings out the manufacturing techniques and costs involved.

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INTRODUCTION

A composite is a material which is made up of two or more distinct (i.e. macroscopic, not microscopic) materials. A familiar composite is concrete, which is basically made up of sand and cement. Polymer composites are plastics within which fibers or particles are embedded. The plastic is known as the matrix, and the fibres or particles, dispersed within it, are known as the reinforcement. The reinforcement is usually stiffer than the matrix, thus stiffening the composite material. This stiffer reinforcement will usually be laid in a particular direction, within the matrix, so that the resulting material will have different properties in different directions. This characteristic is usually exploited to optimize the design.

MATRIX: There are a large number of classes of polymer that can be utilized in fabricating a composite material. The selection of a polymer type is a function of many items including application, cost, fiber type, manufacturing method, supply etc.

Some of the resins that are available include:

- ✓ Polyester
- ✓ Vinyl Ester
- ✓ Epoxy
- ✓ Bismaleimide
- ✓ Polyimide
- ✓ Phenolic
- ✓ Cyanate ester
- ✓ Nylon
- ✓ Polyether imide (PEI)
- ✓ Polyetheretherketone (PEEK)
- ✓ Polyphenylene sulphide (PPS)
- ✓ Polyamide imide (PAI)

FIBRE: The principal choices for fiber reinforcement are:

- ✓ Glass
- ✓ Carbon
- ✓ Aramid
- ✓ Boron

Properties of the composite are greatly influenced by orientation and nature of those fibres.

POLYMER MATRIX COMPOSITES (PMCs):

Polymer matrix composites (PMCs) are materials that use a polymer based resin as a matrix material with some form of fibres embedded in the matrix, as reinforcement. Both thermosetting and thermoplastic polymers can be used for the matrix material. Common

Polymer composite thermosetting matrix materials include:

- ✓ Polyester
- ✓ Vinyl ester
- ✓ Epoxy

Polymer composite thermoplastic matrix materials include:

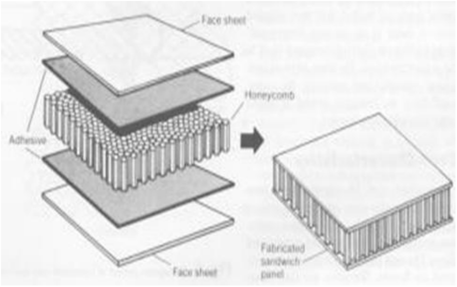
- ✓ PEEK
- ✓ PEI
- ✓ PPS

Reinforcements include:

- ✓ Glass
- ✓ Carbon
- ✓ Aramid fibres

REASON FOR USING POLYMERS:

The primary reason is because of weight saving for their relative stiffness and strength. As an example, a carbon fiber reinforced composite can be compared with its steel counterpart. The carbon fiber composite can be five times stronger than 1020 grade steel while having only one fifth the weights. Aluminum (6061 grade) is much nearer in weight to carbon fiber composite (though still somewhat heavier), but the composite can have twice the modulus and up to seven times the strength.



PROPERTIES:

The matrix protects the strong stiff fibres and the composite material improves on the properties of either the matrix material or the fibres alone. A major driving force behind the development of composites has been to produce materials with improved specific mechanical properties over existing materials.

CORROSION RESISTANCE:

Polymer composites can be designed for excellent corrosion (somewhat of a misnomer) resistance to specific hostile environments. Much emphasis must be placed upon the selection of a suitable resin system when designing against a hostile chemical environment. However, attention to the details of design is needed to ensure that optimum performance is achieved. Good corrosion resistance is not just achieved by selecting an optimum resin. The whole manufacturing process, installation and service life, needs to be optimized.

Composite materials are highly anisotropic and this results in more basic mechanical properties being required for a basic characterization. In addition, their high anisotropy complicates the test methods and gives different properties in tension, compression and shear.

THERMAL CONDUCTIVITY:

The thermal conductivity of composites is often required to determine heat flow conditions. Thermal conductivity properties are directionally independent and can be determined under both steady state and transient heat flow conditions. Transient methods actually are determinations of the thermal diffusivity, from which the thermal conductivity may be derived.

Antistatic agents are added to polymers to reduce their tendency to attract electrical charge. Control of static electricity is essential in certain plastics processing and handling operations, as well as in finished products. Static charges on plastics can produce shocks, present fire hazard and attract dust. The effect of static charge in computer/data processing applications, for example, is particularly detrimental.

COEFFICIENT OF THERMAL EXPANSION

The Coefficient of thermal expansion is very directionally dependent with the CTE in the fiber direction being far smaller than that of the resin. Carbon fibers can have a negative CTE.

ELECTRICAL CONDUCTIVITY:

Most composites do not conduct electricity. It is possible to obtain a degree of electrical conductivity by the addition of metal, carbon particles or conductive fibers. Electromagnetic interference shielding can be achieved by incorporating conductive materials.

SPECIFIC STIFFNESS:

The specific stiffness can be defined as the stiffness of a material divided by the density of material and specific strength can be defined as the strength of a material divided by the density of the material. It is these good specific properties of composites that allow the design of high performance structural components.

DIRECTIONALITY:

Polymer composite material structures can also be engineered so that the directionality of the reinforcement material is arranged so as to match the loading on a given component or structure. In addition, polymer composites are useful in applications where the environment would be detrimental to other materials. The matrix holds the fibers together. A loose bundle of fibers wouldn't be of much use. Also, though fibers are strong, they can be brittle. The matrix can absorb energy by deforming under stress. The matrix adds toughness to the composite. These Fibers have good tensile strength .They usually have high compression strength. The matrix gives compression strength to the composite.

The properties of unidirectional composites are quite different from isotropic materials. Unidirectional materials are highly anisotropic and have exceptional properties in the fibre direction and mediocre properties perpendicular to the fibre directions. There are very few situations where composites are used purely in a unidirectional configuration. In most applications there will be some form of loading away from the direction of the fibres. In this situation, it is only the resin that resists this load which has no reinforcement. Hence composite structures are made by combining unidirectional laminates in different directions to resist these loads. These laminates are called multi directional laminates.

ULTIMATE ELONGATION AND ELASTIC ELONGATION:

Ultimate elongation is the maximum elongation which the polymer can suffer before undergoing cleavage or fracture. Elastic elongation is the percent elongation by which one can reach without permanently deforming polymer. That is, the amounts by which it is stretched and still have the sample snap back to its original length once the stress is released. This is important for materials like elastomer. Elastomers have to be able to stretch a long distance and still bounce back. Most of them can stretch from 500 to 1000 % elongation and return to their original lengths without any trouble.

ICE IMPACT:

In aerospace, sources of ice impact include hailstones and shed-ice. These impact events occur at high velocities since the ice is falling from the sky at terminal velocity or is impacting a moving and/or rotating target. Ice material properties are also of interest, particularly in support of ongoing ice impact material model development activities.

REPLACABILITY FOR METALS:

Many metal articles or components can instead be made from composites, but there are important differences which mean that direct substitution should be made with care. Most engineering materials are essentially isotropic. That is, they have the same properties such as strength and modulus, in any direction.

There may be 'grain' in some metals due to the manufacturing process, but it is only in critical applications that this matters. Most machining or casting processes do not have to take directional differences into account.

Most composites will have very different properties in different directions. This is because, although the matrix material is isotropic, the reinforcement is not. Carbon fibres may be up to 100 times stronger under tension than they are in shear, and the stiffness may differ in the two directions by similar ratios. The properties of the composite will reflect the properties of the reinforcement, so that it can have greatly different properties in different directions. This is exploited in design as manufactured articles rarely require being equally strong in all directions, and composites can achieve this by particular arrangements of the reinforcement. However, a different design procedure is required for composites compared to that required for metals.

Air release:

Most laminating resins, gel coats and other polyester resins might entrap air during processing and application. This can cause air voids and improper fiber wet-out. Air release additives are used to reduce such air entrapment and to enhance fiber wet-out.

EFFECT OF ADDITIVES:

FOAMING AGENTS:

They are chemicals that are added to polymers during processing to form minute cells throughout the resin. Foamed plastics exhibit lower density, decrease material costs, improve electrical and thermal insulation, increase strength-to-weight ratio and reduce shrinkage and part warping.

PLASTCIZERS:

They are added to compounds to improve processing characteristics and offer a wider range of physical and mechanical properties. Slip and blocking agents provide surface lubrication. This results in reduced coefficient of friction on part surfaces and enhances release of parts from the mold.

HEAT STABILIZERS:

They are used in thermoplastic systems to inhibit polymer degradation that results from exposure to heat.

ULTRAVIOLET STABILIZERS:

Both thermoset and thermoplastic composites may use special materials which are added to prevent loss of gloss, crazing, chalking and discoloration, changes in electrical characteristics, embrittlement and disintegration due to ultraviolet (UV) radiation. Additives, which protect composites by absorbing the UV, are called ultraviolet absorbers. Materials, which protect the polymer in some other manner, are known as ultraviolet stabilizers.

FIRE RESISTANCE:

Combustion resistance is improved by proper choice of resin, use of fillers or flame retardant additives. Included in this category are materials containing antimony trioxide, bromine, chlorine, borate and phosphorus.

HYGROTHERMAL BEHAVIOUR:

Composite materials exposed to a liquid for an extended period will eventually become saturated. The absorbed moisture plasticizes and swells the matrix. This reduces the mechanical properties and the glass transition temperature of the composite and hence the maximum use temperature. After time with moisture, the physio-chemical and thermo mechanical properties of composites are further affected by hydrothermal ageing.

Water penetrates the composite via cracks and voids in the matrix and diffuses through the matrix resulting in reversible plasticization.

Moisture will diffuse into the matrix causing swelling and plasticization. These may result in chemical degradation, or swelling stresses which can result in matrix cracking and/or deboning of the fibre/matrix.

Loss of properties of the glass fibre: i.e. water molecules penetrate the glass fibre via micro cracks on the surface so reducing its mechanical properties.

Thermoplastic polymers tend to absorb significantly less water than thermosetting materials, and as such the hydrothermal effect on thermoplastics is negligible.

CHEMICAL RESISTANCE:

Fibre reinforced plastic has been used for many years as a cost-effective material for chemical containers. However, all organic resins are permeable to water, and a number of other liquids to a certain extent. The absorption varies significantly but whereas thermoplastics can be completely dissolved, thermoset materials will just swell.

The material selection depends on the severity of the environment. For weak acids a chlorinated or long chain iso-polyester would be suitable, whereas more aggressive environments such as caustics and most solvents require vinyl ester resins. Vinyl esters are commonly used, as they are more resistant to chemicals than polyesters yet cheaper and easier to manufacture than epoxies. Although epoxies have a greater solvent and thermal resistance than vinyl esters they are more difficult to process and more expensive.

APPLICATIONS:

These materials have their wide range of disciplines. About 30% of all polymers produced each year are used in the civil engineering and building industries. Polymers offer many advantages over conventional materials including lightness, resilience to corrosion and ease of processing. They can be combined with fibres to form composites which have enhanced properties, enabling them to be used as structural members and units. Polymer composites can be used in many different forms ranging from structural composites in the construction industry to the high technology composites of the aerospace and space satellite industries.
The following are some of them:

- ✓ Boating
- ✓ Automotive and rail
- ✓ General Engineering
- ✓ Aerospace
- ✓ Sporting goods
- ✓ Civil Engineering
- ✓ Domestic
- ✓ Medical

MULTIFUNCTIONAL COMPOSITE MATERIALS:

Embedded electrical systems are of interest in many applications, particularly large-sized flying antenna systems. The fatigue and failure of electrical components embedded within dielectric composite materials namely glass/epoxy and are being investigated. A combined experimental and analytical approach has been used to establish a crack tip opening angle (CTOA) based fatigue fracture criterion for predicting the rate of crack growth in copper foils embedded within glass/epoxy laminates.

DETERMINING COST:

Cost is ever present in the engineering equation and it is the balance of cost and performance that determine whether or not to use polymer composites over an alternative structural material option. There are four factors determining the direct costs of producing articles from reinforced polymer composites. These are:

- ✓ Material costs
- ✓ Tooling costs
- ✓ Processing costs
- ✓ Finishing costs

Additionally, there may be a number of indirect costs, such as quality control, health and safety considerations, etc. which need to be taken into account but are not dealt with here.

MANUFACTURING:

The principle behind composite manufacture is the mixing of the reinforcement with the matrix and the solidifying of the matrix using heat and pressure into the net shape desired. With the variety of types of composites there are an associated variety of manufacturing methods including:

- ✓ Wet lay up
- ✓ Spraying
- ✓ Cold press moulding
- ✓ Resin transfer and injection moulding
- ✓ Autoclave manufacture
- ✓ Hot press moulding
- ✓ Pultrusion
- ✓ Filament winding

JOINING TWO MATERIALS FOR REUSABILIY:

When composite structures cannot be manufactured in one piece, joining methods can be utilized. There are several options for joining polymeric composite components with other composite components or with metal components to form complex structures. Bonded joining techniques and mechanical joining techniques are available. If a structure is to be created from multiple components, then decisions on appropriate joining methods must be taken at an early stage in the design to ensure all joins are practical.

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