
DEFINITION

As distinct from chemical compounds and alloys, whose constituents are restricted to definite ratios by weight, a composite material is one comprised of two or more unique separate materials arranged in a ratio designed to suit the requirements of the engineer.

INTRODUCTION

Whereas chemical compounds are the result of electrical bonding between particles of atomic size and alloys the result of solidification from the constituents' liquid states developing electrical bonds between atomic sized particles, composites are the result of the bonding of macrosized materials to provide a new material with the desired properties. For most composites the bonding is physical or mechanical and in many cases the bonding agent is introduced.

A section through a compound or an alloy would require a microscope to separate the constituents but, on a section through a composite, the details of its makeup can be clearly seen with the naked eye.

Examples of composite materials are:

Concrete, asphalt, wood, enamel coated metals, glass reinforced plastics (G.R.P.), resin bonded casting sand, grinding wheels, laminated glass, asbestos reinforced plastics and ceramics, aliclad, sintered metals, plywood, galvanised steel, cermets, painted timber, glazed ceramics, solid core, polymer laminates (laminex, formica etc.), electroplated materials, surface hardened mild steel, bricks etc.

COMPOSITE TYPES

It is convenient to group composites under appropriate headings. The headings most often used are:

1. The agglomerates.
2. The laminates and surface coated materials.
3. The reinforced materials.
4. The dispersion strengthened alloys.

1. THE AGGLOMERATES

These are the composites formed by mixing and bonding relatively small particles to form a larger mass.
They include:

Concrete, asphalts, resin bonded sand, grinding wheels,
sintered metals, cermets, bricks etc.

CONCRETE

This is formed by mixing gravel, sand and portland cement together
and using the necessary water to generate a bond. Refer to Topic 11
for details of the bond reactions.

When correctly mixed, the spaces between the relatively large gravel
particles are occupied by the much smaller sand particles. The spaces
between the sand grains are taken by the very fine cement powder. The
addition of water causes a series of hydration reactions which produce
the silicate gel bonding agent.

Figure 1 shows a cross section of concrete approximately twice full
size.

![Concrete Cross Section](image)

Fig. 1.

The large darker areas are the gravel, the finer dark particles the
sand and the white matrix is the hydrated portland cement gel.

The final strength of the concrete mass depends on:

(i) The relative amounts of gravel, sand and cement.
4:2:1 by volume is a suitable mix for most construction
work.

(ii) The use of evenly graded sharp aggregate and sand which
will pack tightly.

(iii) The effectiveness of the reactions producing the bonding
gel. (Too much water will weaken the final product).

(iv) Correct mixing, laying and curing time. An average
time is about 1 week.

PROPERTIES

(i) Very strong in compression.

(ii) Very weak in tension.

(iii) Brittle.
(iv) High resistance to temperature extremes if a small amount of air in tiny bubble form remains in the set concrete.

(v) Weather resistant.

(vi) Low maintenance.

(vii) Low resilience. Resilience and failure in tension can be greatly improved if steel reinforcement or pre-stressed steel beams are included in the concrete mass.

USES

The main use for concrete is in the building construction industry.

Other uses are roads, bricks, tiles, paths, floor slabs, garden furniture etc.

The chief advantage of concrete is its mouldability. It can be poured to shape in formed moulds on site or pre-cast in moulds and transported to the job.

THE ASPHALTS

Asphalt is a common term used to describe a mixture of crushed rock and asphalt or bitumen loosely bonded with asphalt cement.

The asphalts (or bitumen) are dark coloured semi-solid materials consisting of a mixture of hydrocarbons. They are in the form of a complex emulsion in which the solid material is suspended in an oily viscous medium. They are thermoplastic and it is this property which makes them suitable for their main use, road construction.

Asphalts are divided into natural and manufactured.

The natural asphalts are comprised of a mix of between 10% and 50% fine silica based minerals suspended as a water based emulsion in a matrix of bitumen.

The manufactured or pyrogenous asphalts are by-products of petroleum distillation. They can be processed to form asphalt cement which is a semi-solid substance that changes to its fluid state at temperatures above 150°C.

When used as surfacing for roads, paths, roof tops, sporting fields etc., the mix of fine mineral particles and asphalt bonded with asphalt cement forms a hard, resilient, non-rigid composite which will follow any slight movements in the soil base which supports it. In areas, such as roads which are subject to heavy duty, either rock or concrete is laid as a base.

Figure 2 shows diagrammatically a section of an asphalt composite.
RESIN BONDED SAND

The moulds used for shell moulding (See Topic 5 Page 10) are made by producing a composite of sand and thermosetting resin, usually either phenol or ureaformaldehyde.

The pure sharp sand is mixed with about 5% by weight of resin and heated to above 250°C by the metal pattern, so that the resin melts and flows to fill the spaces between the sand grains. On cooling, the resin sets to form a bond between the sand particles.

GRINDING WHEELS

The abrasive ceramic particles which act as the cutting edges are formed into a composite with glass or resin by melting it so that it fills the spaces between the particles. On setting it acts as a bonding agent.

SINTERED METALS

The sintering or heating of compressed metal particles causes some of the constituents to flow into the spaces between the remaining particles and, when set, to act as a bonding agent for the composite material.

For more details on sintering see Topic 7.

CERMETS

These are composites formed by mixing like sized ceramic and metal particles, in a ratio of about 4:1, compressing the mix in a die then heating it to above the melting point of the metal constituent. On cooling the metal constituent acts as the bonding agent.

Articles thus formed have properties related to both the ceramic and the metal.

They display some ductility, toughness, good shock resistance, reasonable conductivity as well as high temperature strength and hardness.

Some examples of cermet ceramic/metal combinations are:

- Zirconium carbide (ZrC) and iron
- Titanium carbide (TiC) and cobalt
- Tungsten carbide (WC) and cobalt
- Aluminium oxide (Al₂O₃) and chromium
- Molybdenum boride (Mo₂B) and nickel

Cermets are used for hot forging dies, tools for spinning hot metals, edges and tips for high speed, heavy duty cutting tools and jet engine and rocket parts.

Figure 3 shows diagramatically a section of a cermet.
FIRED CLAY BODIES
The high temperatures involved in firing clay bodies produce composites comprised of solid particles held together by a vitreous bond. (See Topic 11).

2. THE LAMINATES AND SURFACE COATINGS
These are the composites formed by bonding two or more layers or sheets of material together. The layers may be of the same material or different materials.

Laminating, layering or coating to form composites is carried out for a number of reasons. In many cases multiple advantages are achieved.

(a) PROTECTION AGAINST DAMAGE OR CORROSION
Composites in this category include:

- Enamel coated metals, alclad, galvanised sheet steel, painted surfaces, electroplated materials, surface hardened mild steel, glazing on ceramics etc.

To be effective the surface layer and the base material must achieve bonding continuity.

In some cases surface adherence is the result of bonding not unlike the bonds between phases in a microstructure. (See Topic 2).

The bonding between the glazing and the base ceramic, galvanising and the sheet steel and vitreous enamel powders onto metal surface are examples. All require heat to fuse the materials together.

In the case of alclad the bonding between the aluminium sheets and the duralumin base is achieved by rolling the assembled layers to the required overall thickness. The rolling causes a welding between the aluminium and the duralumin. Aluminium is much less subject to corrosion than is duralumin.

The bonding for electroplating relies on the atomic sized particles of the depositing metal (copper, nickel, chromium etc.) adhering to the prepared base metal surface and, as the coating develops, to the already in place plating metal.

In other cases the bonding agent must be introduced.

Examples of this are the priming coats applied prior to painting surfaces and the so-called contact adhesives for fastening laminated polymers (laminex etc.) to timber products.

(b) DECORATION
These composites include the veneered timber, plywood and solid core products and the plasticised papers and cardboards.

Decoration is also a benefit of such composites as enamel coated metals, glazed ceramics, painted timbers and electroplated materials already mentioned under the previous heading.

(c) TO IMPROVE MECHANICAL PROPERTIES
Plywood, solid core, laminated glass and surface hardened mild steel are examples of composites developed to improve the mechanical properties of the base material.

For plywood and solid core the tensile and compressive strengths and resistance to the internal stresses due to bending, twisting and shear forces are much higher than in the original wood. (See Topic 12).
By laminating glass and polymer sheeting the tendency of the glass to fail and shatter under impact loading is greatly reduced. The insulation properties of the original glass are also improved. (See Topic 11).

When the surface of relatively soft mild steel is hardened, its resistance to scratching, abrasion and indentation is improved. (See Topic 9).

NOTE: For all the laminates the key to their effectiveness lies in the strength and continuity of the bonding between surfaces.

3. THE REINFORCED MATERIALS

These are the composites which use high strength materials embedded in low strength bases to improve their mechanical properties.

Some examples are:

- Reinforced concrete, reinforced polymers (glass, asbestos, nylon and organic fibres, tape and matting). the dispersion-strengthened alloys etc.

REINFORCED CONCRETE

A concrete beam, suspended as shown in Figure 4, will deflect as indicated.

![Fig. 4.](image)

This deflection will place the top surface in compression and the bottom surface in tension. As already mentioned, concrete is relatively weak in tension and so the failure indicated in the diagram will develop.

To overcome tensile failure, steel rods or beams are suitably located in the concrete mass so that they carry most of the tensile load. See Figure 5.

![Fig. 5.](image)

Reinforced concrete is the most important of the reinforced composite materials. In critical situations, such as suspended load carrying beams the steel is tension stressed prior to the concrete being poured.
When the concrete has cured the external tensile forces on the steel are removed causing the stressed steel rods to place the concrete in compression.

Once in position any loads on the beam must first overcome the built-in compression before any tensile forces develop in the beam. These beams are called pre-stressed concrete beams. See Figure 6.

**Fig. 6.**

**REINFORCED POLYMERS**

The most important of these is G.R.P. This composite uses glass fibre or a tape or matting made from glass fibre to improve the strength properties of the polymer. As seen in Topic 11, fine glass fibres are very strong in tension due to their low surface area.

The most common polymer used with glass reinforcement is one of the polyester resins with suitable additives. (See Topic 10).

A disadvantage of glass as reinforcement is the temperature limitations. At relatively low working temperatures (100°C), the glass fibres become viscous and lose their strength.

G.R.P's are used for roofing sheets, pleasure boat hulls, car and truck body parts, marine fittings, insulation in electrical equipment etc.

Asbestos fibres, textiles and papers are also used as reinforcements in polymers. When used with the resin and vinyl polymers, high levels of electrical insulation and reasonable strength levels can be achieved. When used with the formaldehydes, polyesters (thermosetting) or polyurethanes good electrical insulation is combined with high levels of strength, shock resistance and excellent heat and chemical resistance.

Applications include steam piping, electrical circuit breakers and switchgear, bearings, pulleys, exhaust systems, thermal insulation, jet aircraft, missile and space rocket nose cones and parts.
Organic fibres (cotton, sisal, flax etc.) in the form of webbing or fabric are used to strengthen the phenolic thermosts and rubber, to provide composites with excellent electrical insulation properties and good heat and wear resistance.

Nylon is used in either thread or fabric form to strengthen many polymers. An important use is to reinforce the vulcanised rubber used for motor vehicle tyres.

Properties of reinforced polymers include the strength of the reinforcement combined with the polymer's shock and corrosion resistance, low density, attractive colours, ease of forming and ready availability of raw materials.

4. THE DISPERSION STRENGTHENED ALLOYS

During the heat treatment or work hardening of many alloys, very hard phases develop in the base matrix of the original alloy. Good examples of this are the martensite and bainite phases present in heat treated steel.

These phases, acting as reinforcement, can increase the tensile strength of the original alloy by a factor of up to five.

One obvious disadvantage of these composites is the limits imposed on the working temperature of the material. Since the reinforcing phases were developed by heat treatment they quickly disappear when the temperature rises.