FAQs
April 2023

Composites FAQs.

What are composite materials?

Explaining what composite materials are can have several levels of interpretation. In fact, the definition of a composite material can vary greatly depending on the context in which it is formulated.

In the chemical context, for example, a composite is defined as ‘a multi-component material comprising multiple, different (non-gaseous) phase domains in which at least one type of phase domain is a continuous phase’ (IUPAC ‘Gold Book’ 2019). This definition, for example, could also include a suspension consisting of liquids that are not miscible with each other.

In the field of engineering, however, the definition of a composite material (often abbreviated to ‘composites’) has become established as a material consisting of two or more engineering materials – not soluble in each other and quite distinct – with significantly different physical and/or chemical properties which, when combined together, generate a new material with different characteristics to those of the individual constituents, usually intended for a particular use (e.g. structural or for thermal or electrical insulation). The individual components are always clearly distinguishable within the material structure at the scale of 1 to 100 µm, thus differentiating composites from mixtures of different chemicals, solid solutions (metal or polymer alloys), or homogeneous materials.

The composite material may have better characteristics not only with respect to its constituents, but also with respect to traditional building materials such as metal alloys or ceramics, for example greater stiffness, strength, lightness, durability or even lower cost.

Composite materials do not include concrete and reinforced concrete, masonry, wood or plywood, syntactic foams, laminated iron-steel, bamboo, decorative plastic laminates and multilayer films.

A particular category of composite materials of interest for engineering applications is that of so-called ‘reinforced composites’, in which the properties of the continuous phase (also known as the ‘matrix’) are enhanced by a strong bond with a rigid dispersed phase (known as the ‘reinforcement’) that can be of different natures and shapes. The shape of these reinforcements can vary from fibre to plate to particle size; the most common, however, is that of the fibre-shaped reinforcement.

What are the common types of composite materials?

The most commonly used reinforced composite materials in the field of structural applications, which best meet the requirement for a new material with different characteristics to those of its individual constituents, are composites with a polymer matrix reinforced with synthetic (such as glass, carbon or aramid) or natural (flax, hemp, etc.) engineered fibres. This class of materials is commonly referred to by the acronym FRP (fibre reinforced polymers) and most of the products – almost 90% of the European market (if we exclude injection-moulded thermoplastic matrix composites with short fibres) – have an unsaturated polyester resin as matrix, glass fibre as reinforcement and are known by the common name of ‘fibreglass’.

In composites, however, many combinations of resins and reinforcements are used, and each material contributes to the unique properties of the finished product. The fibre, which is strong but brittle and incoherent, provides high mechanical properties, while the resin, which is more flexible, gives the object its shape, protects the fibres themselves and contributes significantly to the overall tensile, flexural and compressive properties.

FRP may also contain mineral fillers, additives, modifiers or coatings designed to improve the manufacturing process, appearance and performance of the final product. The English acronym used to define fibre reinforced polymer composites (FRP) is often declined in different ways to specify additional material characteristics: for example, a prefix is often used to identify a specific reinforcing fibre, such as glass fibre (GFRP), carbon fibre (CFRP) or aramid fibre (AFRP). Other acronyms have also been developed and their use depends on geographical location, language or market usage, such as fibre reinforced composites (FRC), glass reinforced polymers (GRP), polymer matrix composites (PMC) or fibre polymer composites (FPC).

However, each of these acronyms means the same thing: fibre reinforced polymer composites.

What are the properties of composite materials?

Usually, ‘composite material refers to those materials that possess the following characteristics:

1. consist of two or more distinct materials (phases) with a recognisable microstructure in the 1 to 100 micron scale;

2. at least two of the phases present have physical properties that are “sufficiently” different from each other to impart properties to the composite that are different from those of the constituents and cannot be obtained from each of them separately.

Materials that do not fulfil both conditions will therefore not be considered strictly as belonging to the category of composite materials.

The condition for composites to be considered “reinforced” is instead expressed by the condition that the fibres have at least one mechanical property (e.g. stiffness and/or strength) “sufficiently” greater than those of the matrix. A rough criterion may be that the stiffness of the fibres should be at least 10 times larger than that of the matrix, from which it can be deduced, for example, that glass, carbon and aramid fibres (all with an elastic modulus $E > 70$ GPa) have sufficiently high mechanical properties to serve as reinforcement for polymer matrices ($E < 5$ GPa).

As far as strength values are concerned, the situation is basically the same. The reinforcing fibres mentioned above have values in the order of a few GPa, while for polymer matrices the values are always below 100 MPa.

However, not all fibres possess the same properties. A polyester textile fibre, for example, cannot be considered a reinforcement, since their mechanical properties are of the same order of magnitude as those of the resins used in the manufacture of composites. They can, however, be usefully employed, for example, to reinforce a rubber, which has an elastic modulus approximately 1000 times lower than that of glass polymers.

In general, fibres tend to have a higher strength than the corresponding bulk material because their smaller transverse dimensions reduce the amount of defects present. If the spinning process is also able to control the microstructure of the material – for example by orienting it in the direction of the fibre length – increases in elastic modulus can also be observed in comparison to that of the isotropic material. The latter effect, however, introduces a difference between the properties in the length direction and those in the transverse direction (anisotropy), which must be taken into account when using the fibres.

In order to obtain good adhesion between fibre and matrix during the entire phase of use of the composite material – an essential feature to make the most of the mechanical properties of matrix and reinforcement – the fibres are treated on the surface with chemical agents called ‘sizing’ that coat the surface of the fibres with a very thin layer of interphase material. The presence of this interphase is essential in order to make the dissimilar chemical nature of the fibres and matrix compatible and thus achieve good adhesion between the two. In general, it is logical to expect that the mechanical properties of reinforced composites depend predominantly not only on the properties of the dispersed phase, but also on its quantity within the matrix.

The second important characteristic of the reinforcement is its orientation. With the sole exception of equiaxial particles – which clearly have no prevailing direction – all other types of reinforcement have the possibility of being oriented in one or more spatial directions within the matrix, with important consequences on the mechanical behaviour of the composite.

There are no rules for assigning the reference axes of the body. Taking into account, however, that most structures built with composite materials are “one-dimensional” elements in which one direction prevails over the other two, or “membranous” elements (e.g. foils) for which the thickness is much less than the dimensions in the plane, it is customary to assign the x-direction to the largest dimension (length), the y-direction to the transverse dimension (width) and the z-direction to the thickness of the body itself. In this way, the x-y plane always corresponds to the plane of the panel and the z direction to the thickness of the panel itself. In all cases where the fibres are arranged in a plane containing the x-direction, the orientation angle is by convention defined as the angle θ between the x-direction and the 1-direction of the fibres. Orientation angles may in general be multiple, as generated for example by the superposition of several layers of fibres. In this case, the angles should be listed in the exact order of layering. This list is called the lay-up sequence.

What are composite materials used for?

The application sectors in which composite materials are used are so numerous that they cross all fields of industry and infrastructure: e.g. engines, machine components, electronics, construction, railways, energy production and management, tanks and pressure pipes, offshore structures, biomedical, boats and sports equipment to name a few. The reason for this broadness is the high structural efficiency of these materials, whose structure can be easily adapted to the stress conditions, thereby optimising the properties with respect to the mass (or volume) of the component.

The use of composite materials can therefore be considered particularly advantageous in all those cases where high mechanical properties (stiffness and strength) combined with lightness, shape complexity and/or durability in aggressive environments are required. Furthermore, composite materials easily lend themselves to sensing, for example through the incorporation of fibre optics or other structural monitoring devices, and to the modulation of mechanical, thermal and electrical response thanks to their intrinsic characteristics or the incorporation of actuators, thus representing the ideal field for the development of ‘intelligent’ and/or functional structures.

Composite materials in civil aeronautics have been used in steadily increasing percentages since the 1970s, replacing aluminium alloys to become – in more recent times – the main material. There are several reasons for this. The higher structural efficiency compared to aluminium allows aircraft to have a longer range and lower fuel consumption. The inherent high fatigue resistance linked to the material’s microstructure combined with the absence of corrosion also lead to greater reliability and durability, significantly reducing the number of maintenance and scheduled inspection intervals, which further enhances the aircraft’s cost-effectiveness.

Another example of building large structures with composite materials is wind turbine blades.

In the automotive field, where the productivity required for passenger vehicles is much higher than in aviation, the main innovation in recent years is the BMW i3 and i7 electric cars marketed since 2013. These cars consist of two primary structures: the chassis, made of aluminium, and the passenger compartment, made entirely of carbon fibre composites. This solution has allowed the vehicle’s weight to be significantly reduced, resulting in a range that is largely adequate for use.

Another very important application of composite materials – also in terms of volume – is the use of external bandages for the seismic adaptation of civil housing or infrastructural works or for their structural rehabilitation when they are subject to damage due to seismic events or other disasters.

The technique consists in the application of sheets of composite material on existing structural elements as a sort of “external reinforcement” that corrects and completes any deficiencies in the structure itself without the need for demolition or complex and costly application of additional metal elements that have the disadvantage of weighing down the structure and modifying its appearance. The advantage produced by the containment of weight is particularly significant in view of the fact that the inertial stresses that the building is called upon to withstand in the event of a seismic event are proportional to its mass. Equally evident is the issue of aesthetic preservation of buildings in the conservation of heritage of historical and artistic value. The flexibility of the foils also makes it easy to follow even very complex profiles and paths directly in the application phase, without the need to pre-form the reinforcements before their installation.

For many decades now, composite materials have been the main material for the construction of pleasure boats and superyachts up to more than 60 metres in length, while hulls even longer than 80 metres have been built in the military sector. Sailing yachts also use other elements (such as masts and booms) made entirely of composite materials. In this case, it is not uncommon to see masts over 80 metres high. In spite of their complexity, all these elements (hulls, masts, etc.) can be manufactured using relatively simple equipment such as open moulds through which it is possible to integrate structures and relative localised stiffening elements, even very articulated ones, capable of modulating the resistance factor according to the presence of either concentrated loads (sail boom support elements, centreboard attachment, etc.) or distributed loads. This construction technique, which makes the construction of the hull and the assembly of the various parts fast and efficient, is probably one of the main reasons why composite materials have become the main materials for the nautical industry. The other reasons are, of course, their durability in the marine environment (absence of corrosion) and their exceptional damage tolerance.

There are also many applications of composite materials in sport. All the main shapes that characterise sports equipment can be easily realised using composite materials, thanks to the many possibilities offered by lamination manufacturing technology such as membranes (skis, surfboards, windsurfers and snowboards, slats and wing spars, etc.), tubular structures (tennis and badminton rackets, fishing rods, golf and baseball bats, hockey sticks, high jump poles, masts for sailing boats, bicycle frames, etc.) and shell structures (all types of helmets, golf club heads, hulls, rudders and dinghies of the various classes of sailing boats, etc.).

Are composite materials recyclable?

Composite materials can be recycled, and there are several ways to treat them through circular management.

Composite materials differ from other structural materials due to their unique combination of stiffness, strength and lightness that allows for a reduction in mass, facilitating transport and handling, assembly, installation and – in the case of moving components such as wind turbines or vehicle parts – even the energy demand associated with operation. All these advantages, combined with the superior durability of the material under the most common operating conditions, uniquely identify the environmental benefits of using composites:

- lower energy consumption and lower greenhouse gas emissions;
- longer component life even in the absence of maintenance;
- improved performance and greater safety.

In addition to having the undoubted advantages listed above in terms of durability and efficiency of products in their use phase, composite materials also have numerous possibilities for a circular management of the disposal phase (end-of-life). In fact, the hierarchy promoted by the European Union for the end-of-life treatment of products promotes – before arriving at actual recycling – prevention, repair and reuse strategies that are ideal for composite materials. Composites are in fact repairable, durable and retain their properties for a long time even in the presence of aggressive environments. Should these strategies prove feasible or cost-effective, the market still offers numerous recycling possibilities for composite materials.

To date, the main composite waste treatment technologies with the highest degree of technological maturity for thermoset matrix composites are reprocessing in cement plants, mechanical milling, and pyrolysis, while other processes are currently under development.

Reprocessing in cement plants, which uses glass fibre reinforced composite waste for cement production, enables efficient utilisation of the material by reducing the energy consumption of the process and considerably lowering CO_2 emissions.

Fragmentation with controlled grinding is an energy-efficient and very flexible process for different material flows and types. A partial recovery of the intrinsic properties of composites can also be achieved in this case. There are already many applications, ranging from furniture products, to industrial applications where the recycled material can also perform a reinforcement function with benefits in terms of costs and environmental impact reduction. Finally, pyrolysis of the resin may have a greater environmental impact than the first two process alternatives, but allows the reinforcement fibres to be recovered.

Other resin decomposition processes (solvolysis), although still in the development phase, also allow the recovery of some organic chemical components derived from the thermal decomposition of the resin, which may find application in the production of new composites. Then there are further processes also under development that, although they have a lower degree of technological maturity, may open new frontiers for the high value-added recovery (upcycling) of composite materials, such as electromechanical materials (high voltage pulse fragmentation). Finally, under the impetus of research and innovation, new composite materials specifically designed to be more easily recycled at the end of their life are becoming available on the market. These include composites with thermosetting ‘cleavage’ and/or ‘vitrimer’ matrices or thermoplastic matrix composites obtained by reactive moulding.

For further information about composites circularity visit the Knowledge Hub Sustainability page.