Why use composites?

It's hard to overstate the importance of composite materials in the 21st century. From early uses where they first proved their worth, composites are often the material of choice for high-performance structures. Furthermore, there are some applications (for example MW-scale wind turbine blades) that simply would not be possible without composite materials.

Large wind turbine – only possible with composite materials

In this article, we explore some of the reasons that might drive us to use composites. Of course, nothing is the answer to everything, so we'll also take a look at some of the factors that might limit or prohibit their use.

Reasons to use composites

Let's start by looking at some of the selling points that might cause a designer to select composite materials:

High strength and stiffness, low density: Probably the number 1 reason that most engineers first consider composite materials is that they generally exhibit very favourable strength and stiffness to weight ratios when compared to the alternative metallic options. In particular, a carbon-fibre panel of a given stiffness or strength will tend to be both thicker and lighter than the metallic equivalent, meaning that it will also resist buckling much more effectively. It's primarily for these reasons that the uptake of composites for monocoque type structures in the aerospace and motorsport industries has been so enthusiastic: Load-bearing structures end up weighing less, which means higher performance / reduced fuel burn / longer range.

Excellent fatigue performance: Glass and particularly carbon fibre laminates are capable of excellent fatigue performance when designed properly, meaning in most (but not all) cases that the design of a composite structure is not limited by considerations of fatigue loading. Great fatigue strength is one of the reasons that composites find application in wind energy blades, where fatigue loading is a major design consideration.

Tailored response: Composite materials are strong and stiff in the fibre direction which means that the fibres may be oriented to resist the applied load with great efficiency: In the case of a structural member acting in tension or compression, the majority of fibres would be oriented parallel to the loading direction. For a panel loaded in shear, the fibres would be oriented at +/-45°. It's also possible to design structures with a tailored response. For example, it's desirable for a forward-swept aircraft wing to pitch nose down as it is bent upwards, so preventing an unstable aero-elastic failure. Composite materials enable such a response. Metals do not.


image courtesy NASA

Forward swept wing – only possible with composite materials

Environmental resistance: Fibre reinforced plastic laminates do not rust or corrode, meaning that they are suitable for use in exposed and aggressive environments. It is true that the performance of glass-fibre laminates in particular is subject to degradation following sustained immersion in water, but this issue can normally be covered by the use of appropriate strength knockdown factors. Both carbon and glass-fibre have been used extensively in the manufacture of tidal energy blades, typically designed for 25-30 years immersion in seawater.

Ease of forming complex shapes**:** The tooling required to produce even fairly complex composite mouldings is relatively inexpensive when compared with that required to form steel. In cases where the cost of tooling represents a significant proportion of the overall project cost, (i.e.- low volume production), the use of composites may therefore help to drive down the cost of the project.

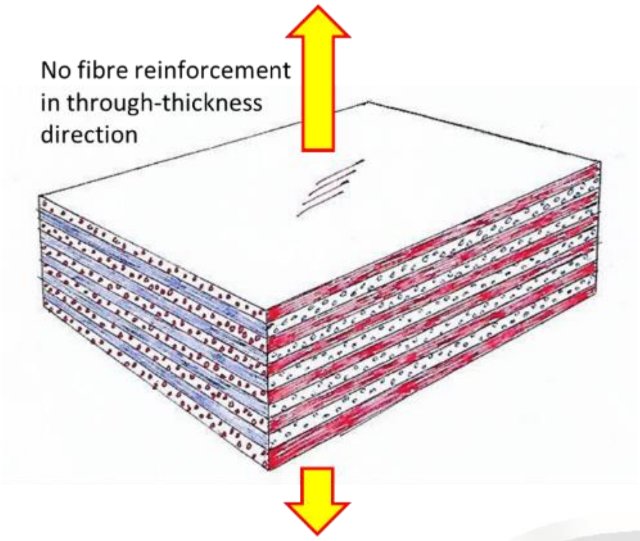
Low component count**:** The ease with which relatively complex forms may be manufactured using composites means that the number of parts in an assembly may be driven down: Complex forms do not need to be built up from a number of simple parts. This confers the significant knock-on benefit of fewer joints (with their associated complexities and weight penalties) and fewer assembly stages. Of course, this claim has its practical limit: The benefits of reduced part count must be balanced against the cost of developing and assuring the quality of complex parts.

The X-factor! Carbon fibre in particular has an attractive finish that implies high-tech and high performance to consumers. Carbon-fibre pops up all over the place where it isn't really needed. Which of us genuinely needs a carbon-fibre pen? - a simple plastic biro works just as well. The lid of the laptop on which this article was written is a carbon-fibre moulding. Does it really need to be? Almost certainly not, but it looks nice!

Limiting considerations

As mentioned earlier, one size rarely fits all, and there are many applications for which composites / fibre reinforced plastics may be less suitable. Even in cases where composite materials do represent an appropriate choice, certain characteristics mean that limitations may apply to the way in which they may be used. Below we'll take a look at some of the usual suspects:

High operating temperatures**:** This is hard to get away from - some operating temperatures are simply too high for fibre-reinforced plastic composites to cope with – you won't find FRP composites at the hot end of a jet engine, for example! Although the fibres themselves are happy enough at high temperatures, the problem lies with the plastic matrix: Once the glass transition temperature (Tg) of the matrix is reached or exceeded, it loses its rigidity and the component loses its mechanical properties. Some high-temperature epoxy matrices may be used at temperatures up to approximately 185°C. Above this, polyimide and bismaleimide (BMI) matrices extend the envelope to approximately 260°C, but beyond this it becomes necessary to move to the highly specialised fields of metal and ceramic matrix composites.



Through-thickness stresses represent a significant issue for composite materials. Most manufacturing methods result in the fibres being oriented parallel to the mould surface. As such, there is no reinforcement running in the through thickness, or 'z' direction. Consequently, the 'z' direction will always be weak, particularly if loaded in tension. Where significant through thickness loading is unavoidable, it's wise for the designer to apply and observe safe stress limits, however these will be much lower than the allowable in-plane limits.

Techniques such as tufting, z-pinning and 3D weaving are available for through-thickness reinforcement, but these should really be viewed as premium solutions to particular local problems.

Impact sensitivity: Composite materials are susceptible to delamination damage resulting from significant handling or in-service impacts. Such damage has the capacity to reduce the strength of a component without leaving a visible witness mark. Therefore, it's really important that the design of a structural part is consistent with assumptions made regarding handling / in-service impacts and inspection regimes.

Component thickness: It can be difficult to produce composite laminates of very great thickness. There is no hard and fast thickness limit (laminates have been produced successfully with thicknesses ~100mm and greater) but the higher the thickness, the more attention will need to be paid to the choice of material, cure cycle, exotherm, debulk ratio, resin shrinkage effects etc.

Production rate: Turnaround time for composite tools tends to be limited by the time required to cure the part. Depending on the resin system, this can vary from minutes to days. Typically, larger mouldings necessarily make use of slower-curing resins whereas smaller parts may use more reactive fast-curing or thermoplastic systems. In any case, manufacturing cycle times associated with composite parts remain significantly higher than the time to press a steel car body panel, for example.

Material cost: The cost of composite material varies greatly from high to low-end applications. It would generally be expected that the materials in a composite structure would cost more than the those in an equivalent metallic construction. It's for this reason that composites tend to be used in applications where their other properties enable the manufacture of products (e.g.- wind turbine blades) that would not otherwise be practical. Composites also frequently find use in applications where they enable significant reductions in the lifecycle cost of a product. Examples include aircraft, where the reduced structural weight enables a significant reduction in fuel burned, and maintenance-free footbridges, where the reduced weight makes for a quicker installation with much reduced disruption to motorists.

Composite footbridge in-situ, image courtesy FiberCore Europe: www.fibercore-europe.com/en/

UV: Generally speaking, an uncoated composite part left outside for many years will not fare well! In applications exposed for any length or time to sunlight, it's normally necessary to apply a UV-resistant coating.

Recyclability: In general, the recycling of composite materials is challenging. The inherent nature of composites means that it is difficult to separate and subsequently re-use its constituents. It's for this reason that the recycling of composites is currently a hot topic within the industry, rightfully absorbing significant research effort. Some manufacturers even offer mat manufactured from recycled carbon fibre. In any case, the environmental effect of composites is best considered in the round: Although composites are difficult to recycle, they are often used in applications that permit greatly reduced fuel burn or the generation of renewable electricity.

Specialist subject: Dabblers beware! The engineering of composite structures and components is very much a specialist subject, full of pitfalls and metaphorical rakes on which to tread. Design, materials, and manufacturing method are deeply interdependent, and there are numerous good practices to be observed in terms of laminate and joint design. Furthermore, the analysis of composite structures is far less straightforward than that of metallics. Numerous potential failure modes must be checked and the correct interpretation of FE calculations requires considerable experience. Therefore, the involvement of a composites specialist (even if it's not Orthotropic!) is advised in any non-trivial composites project.