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Applications of Composite Materials in Aerospace Industry

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ABSTRACT
Composites are becoming increasingly important in the aerospace industry. At least 30–40 per cent of modern airframes are now made of composites, and this percentage is increasing rapidly due to technological advances in the field. Fibre-reinforced polymer composite materials are fast gaining ground as preferred materials for construction of aircrafts and space crafts. This paper gives a review of some of these developments with a discussion of the problems with the present generation composites and prospects for further developments. Although several applications in the aerospace vector are mentioned, the emphasis of the review is on applications of composites as structural materials where they have seen a significant growth in usage. A brief review of composites usage in aerospace sector is given first. The nature of composite materials and special problems in designing and working with them are then highlighted. The issues discussed relate to the impact damage and damage tolerance in general, environmental degradation and long-term durability.

Keywords: aerospace applications, composite materials, fibre-reinforced

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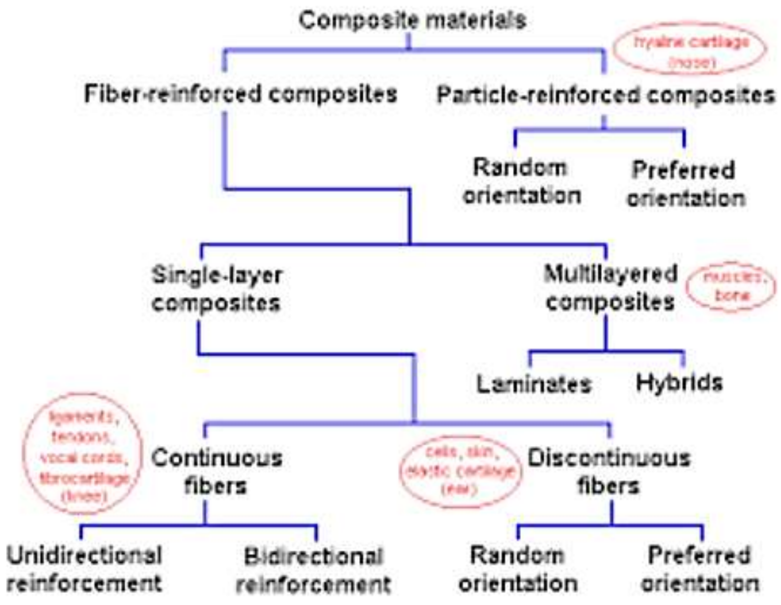
INTRODUCTION
Materials can be classified into the categories: metals, polymers, ceramics and inorganic glasses and composites. Metals lose their strength at elevated temperatures. High-polymeric materials in general can withstand still lower temperatures.

Ceramics outstrip metals and polymers in their favourable melting points, ability to withstand high temperatures, strength and thermal expansion properties, but due to their brittleness they are often unsatisfactory as structural materials.

This lead to the exploration of composites. One may define a composite as material as a materials system which consists of a mixture or combination of two or more micro constituents mutually insoluble and differing in form and/or material composition. Examples of composites are steel reinforced concrete (metals + ceramics), vinyl-coated steel (metals + polymers), and fibre reinforced plastics (ceramics + polymers).

Emergence of strong and stiff reinforcements like carbon fibre along with advances in polymer research to produce high performance resins as matrix materials have helped meet the challenges posed by the complex designs of modern aircraft.

The large-scale use of advanced composites airframes and in current programmes of development of military fighter aircraft, NASA aerospace structures, small and big civil transport aircraft, helicopters, satellites, launch vehicles and missiles all around the world is perhaps the most glowing example of the utilization of potential of such composite materials [1].



THE AEROSPACE STRUCTURES AND FEATURES

Important requirements of an aerospace structure and their effect on the design of the structure are presented in Table 1.

Table 1. *Structure and features of aerospace.*

Requirement	Applicability	Effect
Light weight	All aerospace programmes	• Semi-monocoque construction • Thin walled box or stiffened structures • Use of low density materials • Wood • Al-Alloys • Composites • High strength/weight, High stiffness weight
High reliability	All space programmes	• Strict quality control • Extensive testing for reliable data • Certification: Proof design
Passenger Safety	Passenger vehicles	• Use of fire retardant materials • Extensive testing: crashworthiness
Durability Fatigue and corrosion Degradation: Vacuum Radiation Thermal	Aircraft Spacecraft	• Extensive fatigue analysis/testing • Al-Alloy do not have a fatigue limit • Corrosion prevention schemes • Issues of damage and safe life, life extension • Extensive testing for required environment • Thin material with high integrity
Aerodynamic performance	Aircraft Reusable spacecraft	• High complex loading • Thin flexible wings and control surfaces
Multi-role of functionality	All aerospace programme	• Efficient design • Use: Composite with functional designs
Fly-by- Wire	Aircrafts, mostly for fighters but also some in passenger a/c	• Structure control interaction • Aero-servo elasticity • Extensive use of computers and electronics • EMI shielding
Stealth	Specific military aerospace applications	• Specific surface and shape of aircraft • Stealth coating
All-Weather operation	Aircrafts	• Lightening protection, erosion resistance

USE OF COMPOSITES IN AEROSPACE STRUCTURE

It is to be realized that in order to meet the demands in Table 1, it is necessary to have materials with a peculiar property-set. The use of composites has been motivated largely by such considerations [2]. The composites offer several of these features as given below:

- Light-weight due to high specific strength and stiffness
- Fatigue-resistance and corrosion resistance
- Capability of high degree of optimization: tailoring the directional strength and stiffness
- Capability to mould large complex shapes in small cycle time reducing part count and assembly times: Good for thin-walled or generously curved construction
- Capability to maintain dimensional and alignment stability in space environment
- Possibility of low dielectric loss in radar transparency
- Possibility of achieving low radar cross-section
- These composites also have some inherent weaknesses
- Laminated structure with weak interfaces: poor resistance to out-of-plane tensile loads
- Susceptibility to impact-damage and strong possibility of internal damage going unnoticed
- Moisture absorption and consequent degradation of high temperature performance
- Multiplicity of possible manufacturing defects and variability in material properties

MATERIALS FOR AEROSPACE COMPOSITES

The materials systems which have been considered useful in aerospace sector are based on reinforcing fibres and matrix resins given in Tables 1 and 2, respectively. Most aerospace composites use prepregs as raw materials with autoclave moulding as a popular fabrication process. Oven curing or room temperature curing is used mostly with glass fibre composites used in low speed small aircraft. It is common to use composite tooling where production rates are small or moderate; however, where large numbers of components are required, metallic conventional tooling is preferred. Resin injection moulding also finds use in special components such as radomes. Some of the popular systems are given in Table 2 along with the types of components where they are used in a typical high-performance aircraft [3].

Table 2. *Different types of components with their usage.*

Fibre	**Application areas**
Glass E-Glass S- Glass	• Small passenger a/c parts, air craft interiors, secondary parts, radomes, rocket motors castings. • Highly loaded parts in small passengers a/c.
Aramid • Low modulus • Intermediate • Modulus • High modulus	• Fairings: non-load bearing parts • Radomes, some structural parts; rocket motor casings • Highly loaded parts
Carbon • Standard modulus • Intermediate modulus • High modulus • Ultra-High strength	• Widely used for almost all types of parts in a/c, satellites, antenna dishes, missiles etc. • Primary structural parts in the high-performance fighters • Space structures, control surfaces in a/c • Primary structural parts in high performance fighters, spacecraft

MANUFACTURING APPROACH FOR AEROSPACE STRUCTURES

Carbon/epoxy composites for aerospace use are generally fabricated in a laminated form. The epoxy resin requires curing (hardening) through the application of heat, whilst the stack of plies that forms the laminate requires consolidation to avoid the formation of inter-lamina spaces or -voids. Pressure is applied to the laminate to achieve consolidation. The predominant manufacturing approach for aerospace structures employs pre-preg. Pre-preg material is supplied in rolls or tape, and comprises fibres in woven or UD form preimpregnated with uncured epoxy resin. The material is usually stored in refrigerators to prevent premature curing of the resin at room temperature. The material is cut and laid-up in a tool (mould) by machine, but must then be vacuum bagged by hand prior to the curing process. The cure takes place in an autoclave – a pressurized oven – that subjects the embryonic component to the pressure required to ensure consolidation and the temperature necessary to achieve hardening of the epoxy. Manufacturing and production engineers are searching for ways of reducing the costs, damage and times to produce composite components. Pre-preg materials are generally more expensive, both to buy and to store, than are the component parts (carbon fibre and epoxy resin) singly. Autoclaves are expensive pieces of equipment, and their presence increases the floor space occupied by a factory equipped for pre-preg production. For these reasons alternative forms of the raw materials and manufacturing processes are being sought. Engineers are directing increasing interest at the use of non-crimp fabric (NCF). NCF is dry carbon fibre material, which is cheaper than pre-preg. However, the absence of resin leaves the fibres free to separate from one another, making the material impossible to store or to work with. To hold the dry fibres together they are lightly stitched to form the fibres into a fabric that holds together and makes it workable, yet retains the strength and stiffness advantages of UD pre-preg. In terms of the manufacturing process there is an on-going research effort throughout the industry to eliminate autoclaves. The heated mould tool is one means of achieving the elevated temperature necessary to cure the resin without the use of a separate oven, but this approach still leaves the issue of laminate consolidation unresolved. Vacuum bagging allows a pressure of up to one atmosphere to be applied to the laminate, although this falls short of what can be achieved in an autoclave. For this reason the geometries of component that can utilize this production approach may be restricted. Hopefully the money that is being invested in research in this area will enable such technology to be used in an increasing range of aerospace components [3, 4].

ADVANCES IN MATERIALS FOR COMPOSITES: REINFORCEMENTS

The advanced carbon fibre [2] technology continues to improve harnessing the versatility of carbon fibre and new varieties in terms of better combinations of modulus and strength are becoming available. The developments seem to be in two directions: one, for aircraft applications, is aimed basically at higher strength (>5 GPa) with concurrent improvements in modulus to a moderate level (>300 GPa) and the other, for space applications, is aimed at high modulus (>500 GPa) with moderate strength (3.5 GPa). Fibre is expected to result in composites with better damage tolerance. The developments in aramid fibres also aim at higher modulus with concurrent increase in strength. However, the major thrust in improving reinforcements for composites comes from the requirements of multidirectional weaving. Several processes (weaving, knitting, braiding) have been developed for this purpose and performs with multidirectional woven fibres have now been made. Simplification and cost reductions appear to be the major motives for further developments. The higher properties of basic fibres (such as carbon) cannot, however, be fully exploited in the composite without concurrent developments in the matrix materials and the intermediate products such as prepregs or performs. It is to be noted here that the carbon fibre composites which use a carbon fibre with a strength of 3 GPa as reinforcement result in an allowable stress of only 0.3 GPa in a composite. Significant scope thus exists for translating high fibre properties into high performance of composites [4].

MATRIX RESINS

Significant effort in improving composites is focused on improving matrix materials. The two major concerns mentioned earlier *viz.* impact damage tolerance and hygro thermal degradation; provide the main motivation for improvement. A major direction of improvement appears to be an improvement in the toughness, which should result in higher resistance in to delamination and against impact. High failure strain of matrix resin would help in translating the higher performance of the improved fibre to the composite. Higher resin shear modulus would help in achieving better transfer of load from fibre to resin and again to fibre and should therefore improve compression strength. For polymeric materials a possible figure of 5 GPa should be achievable as against the current resins with shear modulus of about 2 GPa. As far as hygrothermal degradation is considered, newer systems based on cynate ester look very promising and some of these have already found some application. Another route being investigated is the use of thermoplastic resins and their blends. Poly-ether-ether-ketone (PEEK) has been considered very promising, but the industry needs to resolve the problems associated with high temperature (>350°C) processing of a material. Current approaches to new resins appear to be directed towards producing polymeric systems which can be processed in the way composites industry is used to (such as autoclave curing up to 180°C) [4].

THE FUTURE OF COMPOSITES IN AEROSPACE

With ever increasing fuel costs and environmental lobbying, commercial flying is under sustained pressure to improve performance, and weight reduction is a key factor in the equation.

Beyond the day-to-day operating costs, the aircraft maintenance programs can be simplified by component count reduction and corrosion reduction. The competitive nature of the aircraft construction business ensures that any opportunity to reduce operating costs is explored and exploited wherever possible. Competition exists in the military too, with continuous pressure to increase payload and range, flight performance characteristics and “survivability”, not only of airplanes but of missiles, too. Composite technology continues to advance, and the advent of new types such as basalt and carbon nanotube forms is certain to accelerate and extend composite usage. When it comes to aerospace, composite materials are here to stay [5].

ADVANTAGES OF COMPOSITES IN AEROSPACE

We have already touched on a few, such as weight saving, but here is a full list:

- Weight reduction – savings in the range 20%–50% are often quoted.
- It is easy to assemble complex components using automated layup machinery and rotational moulding processes.
- Monocoque (“single-shell”) moulded structures deliver higher strength at much lower weight.
- Mechanical properties can be tailored by “lay-up” design, with tapering thicknesses of reinforcing cloth and cloth orientation.
- Thermal stability of composites means they do not expand/contract excessively with a change in temperature (for example a 90°F runway to –67°F at 35,000 feet in a matter of minutes).
- High impact resistance – Kevlar (aramid) armour shields planes, too – for example, reducing accidental damage to the engine pylons which carry engine controls and fuel lines.
- High damage tolerance improves accident survivability.
- “Galvanic” – electrical – corrosion problems which would occur when two dissimilar metals are in contact (particularly in humid marine environments) are avoided.
- Combination fatigue/corrosion problems are virtually eliminated [5].

CONCLUSIONS

Since the invention of composite materials, aerospace industry has shown significant use of it in building different parts first to almost most of the structural parts and use of it is rapidly growing. The main aspect we need to keep in mind that strength and stiffness are major considerations for aircrafts whereas stiffness and low coefficient of thermal expansion are major considerations for space applications.

Hence, we can finally conclude that Composite materials offer high fatigue and corrosion resistance. Composite materials have high strength to weight ratio. So, they are best suited for various aerospace applications.

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