

## **APPLICATIONS OF COMPOSITE MATERIALS IN AEROSPACE**

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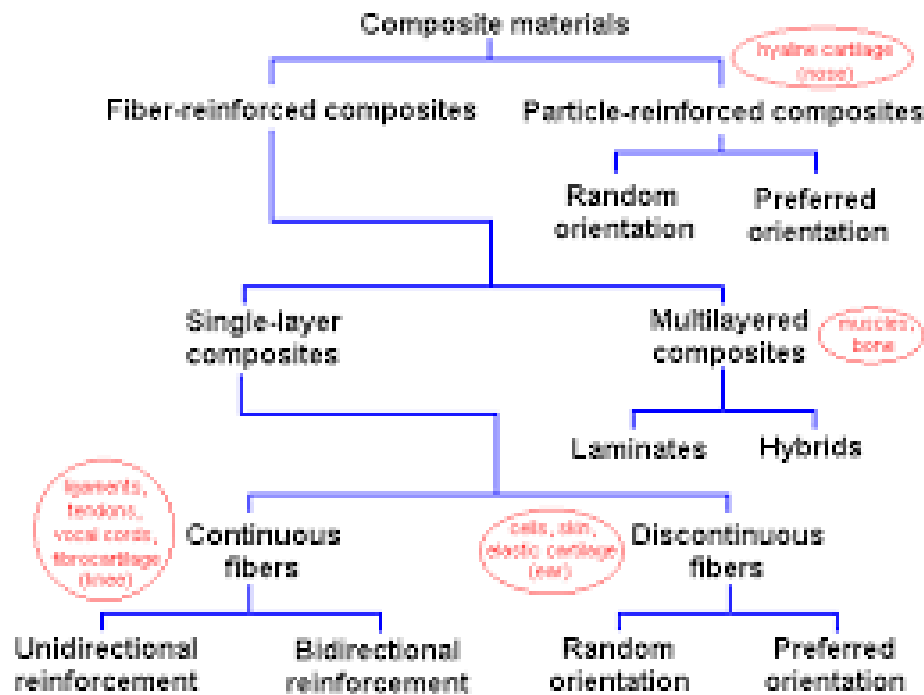
### **ABSTRACT**

*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. Fiber-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: Composite Materials, Aerospace Applications, Fiber-Reinforced**

### **I. 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 favorable 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), fiber 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 [1] and in current programmes of development of military fighter aircraft, NASA aerospace structures [3], 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.



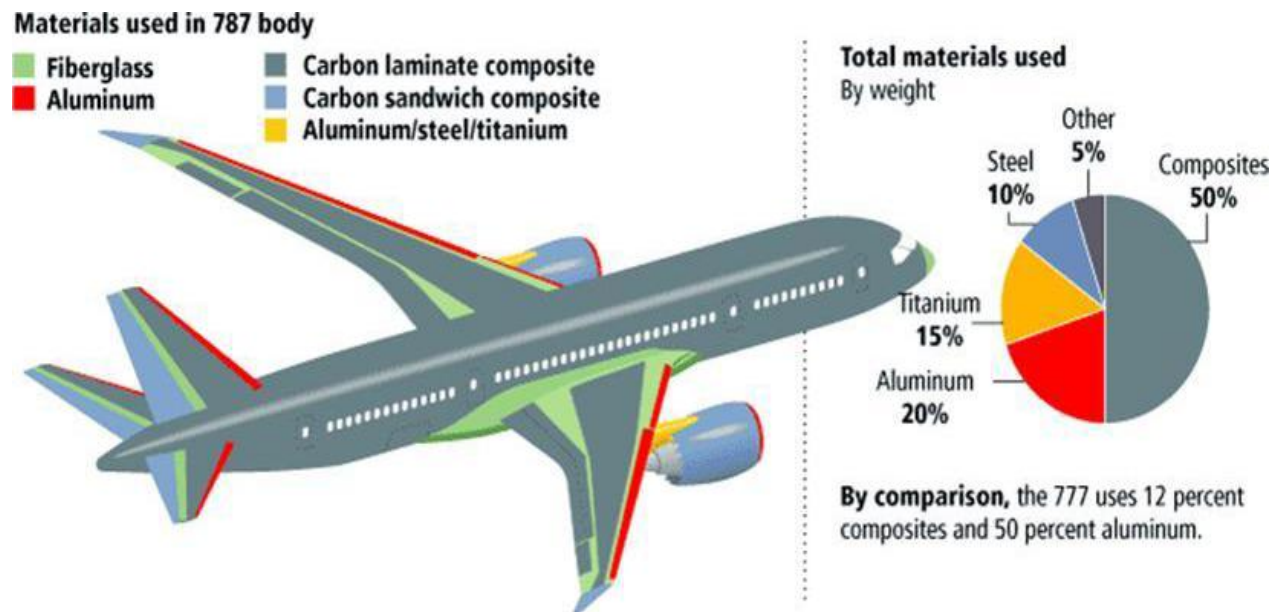
**II. THE AEROSPACE STRUCTURES AND FEATURES**

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

table1

**Table 1.** Features of aircraft structure.

Requirement	Applicability	Effect
• Light-weight	All Aerospace Programmes	<ul style="list-style-type: none"> <li>▪ Semi-monocoque construction</li> <li>* Thin-walled-box or stiffened structures</li> <li>▪ Use of low density materials:</li> <li>* Wood * Al-alloys * Composites</li> <li>▪ High strength/weight, High stiffness/weight</li> </ul>
• High reliability	All space programmes	<ul style="list-style-type: none"> <li>▪ Strict quality control</li> <li>▪ Extensive testing for reliable data</li> <li>▪ Certification: Proof of design</li> </ul>
• Passenger safety	Passenger vehicles	<ul style="list-style-type: none"> <li>▪ Use of fire retardant materials</li> <li>▪ Extensive testing: Crashworthiness</li> </ul>
• Durability-Fatigue and corrosion Degradation: Vacuum Radiation Thermal	Aircraft Spacecraft	<ul style="list-style-type: none"> <li>▪ Extensive fatigue analysis/testing</li> <li>* Al-alloys do not have a fatigue limit</li> <li>▪ Corrosion prevention schemes</li> <li>▪ Issues of damage and safe-life, life extension</li> <li>▪ Extensive testing for required environment</li> <li>▪ Thin materials with high integrity</li> </ul>
• Aerodynamic performance	Aircraft Reusable spacecraft	<ul style="list-style-type: none"> <li>▪ Highly complex loading</li> <li>▪ Thin flexible wings and control surfaces</li> <li>* Deformed shape-Aero elasticity * Dynamics</li> <li>▪ Complex contoured shapes</li> <li>* Manufacturability: N/C Machining; Moulding</li> </ul>
• Multi-role or functionality	All Aerospace programmes	<ul style="list-style-type: none"> <li>▪ Efficient design</li> <li>▪ Use: composites with functional properties</li> </ul>
• Fly-by-wire	Aircrafts, mostly for fighters but also some in passenger a/c	<ul style="list-style-type: none"> <li>▪ Structure-control interactions</li> <li>* Aero-servo-elasticity</li> <li>▪ Extensive use of computers and electronics</li> <li>* EMI shielding</li> </ul>
• Stealth	Specific military aerospace applications	<ul style="list-style-type: none"> <li>▪ Specific surface and shape of aircraft</li> <li>* Stealth coatings</li> </ul>
• All-Weather operation	Aircraft	<ul style="list-style-type: none"> <li>▪ Lightning protection, erosion resistance</li> </ul>



### III. 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.

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

### IV. MATERIALS FOR AEROSPACE COMPOSITES

The materials systems which have been considered useful in aerospace sector are based on reinforcing fibers and matrix resins given in table 2 and 3, 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 number 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 4 along with the types of components where they are used in a typical high-performance aircraft.

Fibre	Density (g/cc)	Modulus (GPa)	Strength (GPa)	Application areas
<b>Glass</b>				
E-glass	2.55	65-75	2.2-2.6	Small passenger a/c parts, air-craft interiors, secondary parts; Radomes; rocket motor casings
S-glass	2.47	85-95	4.4-4.8	Highly loaded parts in small passenger a/c
<b>Aramid</b>				
Low modulus	1.44	80-85	2.7-2.8	Fairings; non-load bearing parts
Intermediate modulus	1.44	120-128	2.7-2.8	Radomes, some structural parts; rocket motor casings
High modulus	1.48	160-170	2.3-2.4	Highly loaded parts
<b>Carbon</b>				
Standard modulus (high strength)	1.77-1.80	220-240	3.0-3.5	Widely used for almost all types of parts in a/c, satellites, antenna dishes, missiles, etc.
Intermediate modulus	1.77-1.81	270-300	5.4-5.7	Primary structural parts in high performance fighters
High modulus	1.77-1.80	390-450	2.8-3.0 4.0-4.5	Space structures, control surfaces in a/c
Ultra-high strength	1.80-1.82	290-310	7.0-7.5	Primary structural parts in high performance fighters, spacecraft

**Table 3 Polymeric Matrices Commonly Used in Aerospace Sector**

Thermosets				Thermoplastics
Forms cross-linked networks in polymerization curing by heating				No chemical change
Epoxies	Phenolics	Polyester	Polyimides	PPS, PEEK
<ul style="list-style-type: none"> <li>▪ Most popular</li> <li>▪ 80% of total composite usage</li> <li>▪ Moderately high temp.</li> <li>▪ Comparatively expensive</li> </ul>	<ul style="list-style-type: none"> <li>▪ Cheaper</li> <li>▪ Lower viscosity</li> <li>▪ Easy to use</li> <li>▪ High temp usage</li> <li>▪ Difficult to get good quality composites</li> </ul>	<ul style="list-style-type: none"> <li>▪ Cheap</li> <li>▪ Easy to use</li> <li>▪ Popular for general applications at room temp</li> </ul>	<ul style="list-style-type: none"> <li>▪ High temp application 300°C</li> <li>▪ Difficult to process</li> <li>▪ Brittle</li> </ul>	<ul style="list-style-type: none"> <li>▪ Good damage tolerance</li> <li>▪ Difficult to process as high temp 300-400°C is required</li> </ul>
<ul style="list-style-type: none"> <li>▪ Low shrinkage (2-3%)</li> <li>▪ No release of volatile during curing</li> </ul>	<ul style="list-style-type: none"> <li>▪ More shrinkage</li> <li>▪ Release of volatile during curing</li> </ul>	<ul style="list-style-type: none"> <li>▪ High shrinkage (7-8%)</li> </ul>		
<ul style="list-style-type: none"> <li>▪ Can be polymerized in several ways giving varieties of structures, morphology and wide range of properties</li> </ul>	<ul style="list-style-type: none"> <li>▪ Inherent stability for thermal oxidation</li> <li>▪ Good fire and flame retardance</li> <li>▪ Brittle than epoxies</li> </ul>	<ul style="list-style-type: none"> <li>▪ Good chemical resistance</li> <li>▪ Wide range of properties but lower than epoxies</li> <li>▪ Brittle</li> <li>▪ Low T<sub>g</sub></li> </ul>		
<ul style="list-style-type: none"> <li>▪ Good storage stability to make prepregs</li> </ul>	<ul style="list-style-type: none"> <li>▪ Less storage stability-difficult to prepreg</li> </ul>	<ul style="list-style-type: none"> <li>▪ Difficult to prepreg</li> </ul>		<ul style="list-style-type: none"> <li>▪ Infinite storage life. But difficult to prepreg</li> </ul>
<ul style="list-style-type: none"> <li>▪ Absolute moisture (5-6%) causing swelling and degradation of high temp properties</li> <li>▪ Also ultra violet degradation in long term</li> </ul>	<ul style="list-style-type: none"> <li>▪ Absorbs moisture but no significant effect of moisture in working service range</li> </ul>	<ul style="list-style-type: none"> <li>▪ Less sensitive to moisture than epoxies</li> </ul>		<ul style="list-style-type: none"> <li>▪ No moisture absorption</li> </ul>

**V. 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 pre-impregnated 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 pressurised 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 [4] and times to produce composite components. Prepreg 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 utilise 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.

## **VI. ADVANCES IN MATERIALS FOR COMPOSITES : REINFORCEMENTS**

The advanced carbon fiber [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). Fiber is expected to result in composites with better damage tolerance. The developments in aramid fibers 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 fibers have now been made. Simplification and cost reductions appear to be the major motives for further developments.

The higher properties of basic fibers (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 fiber composites which use a carbon fiber 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 fiber properties into high performance of composites.

## **VII. 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 fiber to the composite. Higher resin shear modulus would help in achieving better transfer of load from fiber to resin and again to fiber 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 hygro thermal degradation is considered, newer systems based on cyanate 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 0C) 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 0C).

## **VIII. CFRPS FUTURE: THE NANOPARTICLES**

Composites repair — and the nature of CFRP materials themselves — could eventually be revolutionised if current research into the use of electrospun carbon nanotubes and nanofibres, and electrospun silica nanofibres, pays off as researchers hope. By seeding resin matrices with carbon nanotubes, which Kelkar says form the hardest materials currently known to humanity and require just a 0.15 per cent concentration within ‘Solgel’ resin made from tetraethyl ortho silicate, manufacturers could create CFRPs in which the carbon nanoparticles bind the layers of the carbon-fibre ply directly together. Just 80-120 nanometres in diameter, the electrically charged nanoparticles would bind directly to adjacent plies – each given an electrical charge in advance, to allow binding of the oppositely charged nanoparticles. This would create a “velcro” effect which would reduce reliance on the binding properties of the resin matrix, producing CFRPs that are far stronger, more impact resistant, and lighter than those known today. CFRP nanoparticle research is still in its early stages, but Bowers also sees big opportunities for carbon nanofibre patches for advanced repair of CFRP structures. Such patches would greatly increase the surface contact area available for bonding and do away with today’s Catch-22 need to delaminate additional areas in a CFRP aircraft part in order to repair a delaminated area of the structure

## **IX. CONCLUSIONS**

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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