

Polymer composites: a blessing to modern aerospace engineering

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ABSTRACT

Modern aerospace industry is highly progressive and polymer composite materials have a positive and significant impact on it. This paper demonstrates details about the components of advance polymer composites, its properties and its uses in aerospace industries. Polymer composites are highly efficient and environment friendly. Traditional materials are susceptible to fatigue and corrosion when composite materials provide resistance to both of this along with its significant amount of weight reduction. Due to high strength and stiffness of its fiber, polymer composite provides high “strength to weight” & “stiffness to weight” ratios. Apart from this, they possess good shear properties and low density. As a result, new generation aerospace engineers and aircraft designers are turning to polymer composite materials to make their flying vehicle and aircraft lighter, stronger and of course more fuel efficient. Our paper will briefly describe about the uses of fiber reinforced polymer composites in aerospace industry and how does it consider as a blessing in this field.

Key Words: Polymer composites, aerospace engineering, fiber, aircraft

1. Introduction

A Composite material is a material system composed of two or more macro constituents that differ in shape and chemical composition and which are insoluble in each other. A Composite material is a material system composed of two or more macro constituents that differ in shape and chemical composition and which are insoluble in each other.

The term composite is often used both in the modern context of Fiber Reinforced Plastics (FRP) and also in the wider context to cover honeycomb structures and bonded metal laminates for primary structural applications. The fibers or matrix (resin) alone cannot be used for any applications because of the limitations in other properties. The fibers provide the stiffness, and the matrix provides the glue to produce a stiff structure that is very light. Plastics and fibers generally are less dense than the metals, but the fibers have greater stiffness, providing for a larger stiffness-to-weight ratio. Fibers are thin and integrity is not maintained. Fibers are comparatively heavier. In matrix materials the modulus and strength values are less and hence matrix alone cannot be used for any structural applications. But when these two materials are combined we get a composite material which is light weight, stiff, strong and tough. Beyond doubt, the new material here we are developing is much more suitable for special purpose (light weight & strong) than compared to the previous one we got.

2. Why Aerospace?

‘Safety’ and ‘security’ are the most important words in the field of aerospace. Imagine a structural failure in a car and an airplane. If the skin of the car gets ripped off while driving no disaster is going to happen. But in the case of the aircraft, a great disaster will occur. Let’s see the following pictures:



Aloha Airlines Boeing 737

Fig.1 Fuselage damage to Aloha Airlines Flight 243, April 1988

Besides these, the performance of an airplane is highly influenced by its weight and overloading it will cause serious problem. By using composite materials, we can overcome this problem. Aircraft operate in very corrosive environment and inspection for corrosion

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damage are carried out often. Composites don't corrode. They also help to reduce the development of the crack.

3. Components of advanced polymer composite

Advanced polymer composites generally contain reinforcing fibers. They are in the form of continuous filamentary tows or fabrics and properly formulated polymeric matrices. Structural adhesives (mostly in the form of supported or unsupported film) and honeycomb cores are also used for making sandwich structures and metallic laminates.

3.1 Fibers

Fibers are widely used as reinforcements. Glass, aramid and carbon fibers are in extensive use amongst the fibers available. Boron or other exotic fibers are also used in modest quantities for applications requiring very high service temperatures like the ones which we need for the skinning of the aircrafts. The properties of glass, aramid and carbon fibers are given in the tables 1 to 5.

Table 1 typical properties of glass fibers

Fiber	'E' glass	'R' glass	'D' glass
Density(g/cc)	1.44	1.38	1.41
Tensile strength(MPa)	3600	3620	3447
Tensile Modulus(GPa)	83	127	175
Elongation of break(μm)	4	1.85	2.9
Filament diameter (μm)	-	-	-

Table 2 typical properties of aramid fibers

Fiber	Kevlar 29	Kevlar 49	Kevlar 149
Density(g/cc)	1.44	1.38	1.41
Tensile strength(MPa)	3600	3620	3447
Tensile Modulus(GPa)	83	127	175
Elongation of break(μm)	4	1.85	2.9
Filament diameter (μm)	-	-	-

Table 3 properties of high tensile carbon fiber (2)

Fiber	T-300	T-400	T-800
Density(g/cc)	1.75	1.80	1.81
Tensile strength(MPa)	3528	4412	5588
Tensile Modulus(GPa)	230	250	294
Elongation of break(%)	1.5	1.8	1.9

Table 4 properties of high modulus carbon fibers

Fiber	M-30	M-40	M-50
Density(g/cc)	1.7	1.81	1.91
Tensile	2920	2744	2450

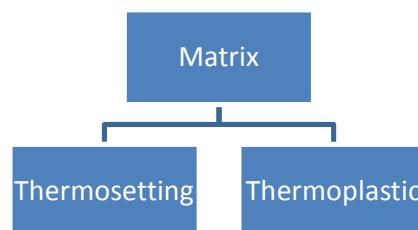
strength(MPa)			
Tensile modulus(GPa)	294	392	492
Elongation of break(%)	1.3	0.6	0.5
Filament diameter(μm)	6.3	6.5	6.3

Table 5 properties of high modulus high strain carbon fibers

Fiber	M 35J	M 40J	M 46J
Density(g/cc)	1.70	1.77	1.84
Tensile Strength(MPa)	5000	4410	4210
Tensile Modulus(GPa)	343	384	440
Elongation of break(%)	1.6	1.2	1.0
Filament Diameter(μm)	5.2	6.2	5.1

3.2 Matrix

Matrices are holders in which fibers are embedded. A matrix acts as binder which surrounds the fibers. For example; when we considering carbon fiber reinforced polymer, carbon fiber is the filler and polymer is the matrix. Matrix properties like Stress-Strain behavior & adhesion properties are important factors which mostly determine the ability of the matrix to distribute stresses. Polymer Matrix can be divided into two groups –



Both type of matrix are greatly used in industrial applications but thermoplastic system is preferred over thermosetting because of no involvement of chemical reaction as it results in release of gas or heat.

(1) Thermosetting

In a thermosetting resin, the raw uncured molecules are cross linked through a catalytic chemical reaction. Through this reaction they are converted into hard brittle solids, creating strong bonds between one another through the formation of three dimensional networks of polymer chains. Once a thermosetting composite is formed; it cannot be reformed or reversed. That is why recycling of thermosetting composite is difficult. Thermosetting resins have excellent properties like resistance to solvents, corrosives, heat and high temperature and also have good fatigue strength, elasticity and adhesion properties. Epoxy resin, unsaturated polyester resin and vinyl ester are the most used thermosetting polymer matrices. Epoxy resins are

better in case of stiffness properties as compared to polyester resins. The interface bond strength between epoxy resin and filler is also greater than the polyester thermosetting.

Table 6 Properties of epoxy and polyester

Property	Epoxy	polyester
Viscosity at 25°C $\mu(\text{Cp})$	12000-13000	250-350
Density	1.16	1.09
Heat Distribution Temperature(HDT)	50	54
Flexural Strength(MPa)	60	45
Tensile Strength(MPa)	78	40
Maximum elongation	4	1

Vinyl ester resins offer good process ability for liquid processing techniques such as RTM.

(2) Thermoplastic

Thermoplastics are of very high molecular weight and their strength and stiffness are emerged from the properties of their monomer units. Amorphous and Crystalline polymer's properties have profound effect on the properties of thermoplastic composites. For Amorphous polymers chain slippage occurs and it leads to high strain to failure, toughness and damage tolerance. Crystalline polymers have increased strength and temperature resistance. Some examples of Amorphous and Crystalline matrices are as follows

Table 7 Examples of amorphous & crystalline matrices

Amorphous	Crystalline
ABS	Nylon 6/6(etc)
PC	PPA
PSU	Acetal(POM)
PEI	PE
PES	PPS
PS	PEK

Table 8 Comparison of mechanical properties

Properties	polycarbonate	polypropylene
Density mg/m^3	1.14-1.31	0.89-0.92
E modulus GPa	2.21-2.44	0.9-1.35
Ultimate strength MPa	65-72.4	17.2-37
Yield strength MPa	58.6-70	20.7-37.2
Tensile strength MPa	6-50	5-37
Max elongation(%)	10-125	10-600

4. Properties of Matrix

It is undoubtedly true that the high strength of composites is largely dependent on the fiber

reinforcement but the importance of matrix material cannot be avoided as it supports the fibers and distribute the load evenly on the fibers.

The desired properties of matrix material for the formation of a good composite are as follows-

- High toughness
- Room temperature cure preferable
- Low moisture absorption
- Low shrinkage
- Low thermal expansion
- Higher elastic modulus(more than fiber)
- Excellent chemical resistance
- Easily process able
- Dimensional stability

4.1 Thermal Properties

Polymer matrix determines the elevated temperature properties and the maximum use temperature of composite material. Glass Transition Temperature (T_g) is an important parameter for dimensional stability of a composite under influence of heat; it also has effect on most of the physical properties of matrix system. The polymer softens as T_g is approached. There are many different ways to measure T_g such as using DSC (Differential Scanning Calorimeter) apparatus, HDT technique.

4.2 Toughness

In aerospace applications high elasticity modulus, high strength and greater damage tolerance of composites are preferred. In polymer matrix composites, the transverse modulus is dictated by the matrix modulus while the longitudinal modulus is dictated by the fiber modulus. That's why transverse strength and shear strength is matrix dominated. However, for a brittle matrix toughness can be achieved by several processes. One of them is by using reactive dilute but in this process the high temperature withstanding capability is lost. Another way is inclusion of dispersed phase in the glassy matrix.

C1: 120C curing epoxy based system not formulated for toughness

C2: 175C curing system based on widely used MY 720 and DD

Here in the following figure we can see a comparison of Toughness of carbon fiber composites based on their toughness. As in aerospace or aeronautical engineering purpose the toughness of the material that we are going to use it should be high enough so special care should be taken while selecting the material. A composite material that may have posses other significant properties required for use in aerospace/aeronautical purpose but wit out being it blessed by the properties of enough toughness definitely it will not be considered as an idle material for this special track of engineering. So the toughness of the selected material should be high enough to satisfy the aeronautical/aerospace engineers.

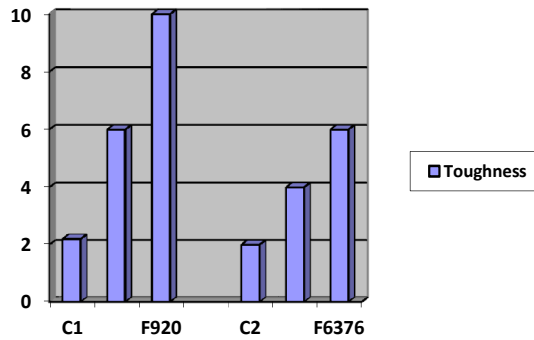


Fig.2 Comparison of toughness of carbon fibre Composites

Here,

C1: 120C curing epoxy based system not formulated for toughness

C2: 175C curing system based on widely used MY 720 and DD

4.3 Humidity and Chemical Resistance

The material selection for the generation of a composite for a particular application largely depends on the severity of the environment. For aggressive environment resins are preferred. Although epoxies have a greater solvency and thermal resistance than vinyl esters, they are difficult to process and more expensive. That's why vinyl ester is mostly used in industrial sectors.

All polymers generate heat and toxic smoke when exposed to fire. However when composites contain upto 70% fiber(by weight) which are non-combustible they are almost fire resistant.

Recent Development in Matrices-

Toughening of a resin usually degrades its yield strength, modulus and Tg. To overcome these problems and for the development of matrices of improved fracture toughness and impact performance and straight up cure cycle; R&D oriented manufacturers have developed a number of matrices which can meet the needs of new demanding aerospace sectors. Composite properties of these matrices are given below in the table.

Table 9 Composite properties of matrix

Matrix and fiber	0° Laminate Properties			
	Tensile strength	Tensile Modulus	ILSS,MPa	G _{IC} (Tough Ness)
F914+T300	1650	135	118	350
F6376+1M6	2696	172	131	
F924+T800	2610	169	130	666
VxM18+M 40JB	2370	221	84	

5. Sandwich Structures

In aerospace industry the effectiveness of composite materials in reducing component weight and increasing fuel economy has greatly been proved. The idea of sandwich structure has become increasingly popular because of the development of man-made cellular materials.

Sandwich structure consists of

- A pair of thin stiff, strong skins(faces, facings or covers)
- A thick, lightweight core to separate skins & carry the loads from one skin to other
- An adhesive attachment which is capable of transmitting shear and axial loads to and from the core.Sandwich structures are very light and stiff which are the main demands of aerospace industry.

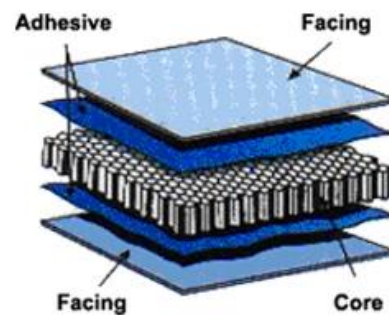


Fig.3 An Illustration of layer orientation of a sandwich structure

6. Advantages of carbon fiber composites

There are various advantages of using advanced composite material specially carbon fiber composite material in aerospace industries as well as others engineering. For example,

1. High resistance to fatigue and corrosion is provided by advanced carbon fiber composite.
2. Composite materials provide high “strength to weight” or “stiffness to weight” ratio. So, weight savings are significant ranging from 25-45% of the weight of the traditional metallic machine design.
3. Composite provides high resistance to impact damage and improve torsional stiffness.
4. Manufacturing and assembly are simplified because of part integration and thereby reducing cost in aerospace industries.
5. Improved friction and wear properties.
6. Composite makes it easy to tailor the basic material properties of a laminate which has allowed new approaches to the design of aero elastic flight structure.

7. Application of composites in aerospace

Composite materials are widely used in the aircraft manufacturing industries and it has allowed the aerospace engineers to overcome the obstacles that have been faced by them when they used the traditional materials individually. As the polymer composite provides the properties of light weight, high temperature resistance etc. so that during the last few decades its application in aerospace industry has rapidly increased to design high performance and economical aircraft. Boeing a leading aircraft manufacturing industry has used a significant amount of composite at their new passenger aircraft “Boeing 787/Dream liner”. The following figure shows us the amount of composite with respect to other materials used in Boeing 787/Dream liner.

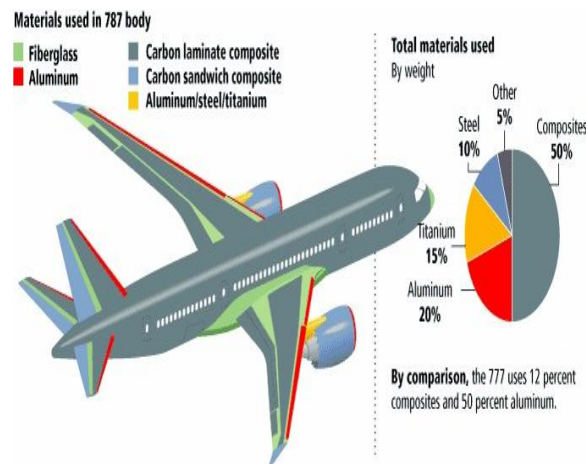


Fig.4 Percentages of composite material along with others in Boeing 787/Dream liner

The figure shows that now a day's around 50% material used in Boeing 787 is composite material with comparison to the Boeing 777 which used only 12% of composite and 70% aluminum. Apart from aircraft, now a day's for design and manufacturing rocket and missiles the new generation aerospace engineers are widely using composite of carbon, aramid and glass. Carbon-carbon composites are used for manufacturing the nose tips and heat shields of reentry vehicles.

8. Blessing to modern aerospace engineering

Polymer composite has proved as a blessing to modern aerospace/aviation industries. For a flying vehicle it is most important to be lighter than air and at the same time it should be strong enough to withstand the gust load and other aerodynamic loads which impose on it. But it was very difficult for the aerospace engineers to select such a material which will provide enough strength to weight ratio when they worked with the traditional individual material. But this problem was solved by the grace of polymer composite which is very much light (important for fuel efficiency) and provide enough strength against the gust and aerodynamic loads. Now with the help of a comparison between Boeing 777

(launched in 2000) and Boeing 787 (launched in 2007) we will prove our statement regarding the debt of polymer composite materials in aerospace industries.

Table 10 Comparison between Boeing 777 & 787

Boeing 777	Boeing 787/ Dream liner
Launched in 2000	Launched in 2007
12% Composites	50% Composites
50% Aluminum	20% Aluminum
8% Titanium	15% Titanium
20% Steel	10% Steel
10% Others	5% Others

Because of using 50% polymer composite material instead of using greater amount of aluminum, steel or others traditional materials makes Boeing 787 almost 20% more fuel efficient and 35,000 lbs lighter compared to its previous origin Boeing 777. That is how polymer composite contributes to modern aerospace industries.

Conclusion

It is always important to choose the right material for right job. For example, In order to designing a commercial gas cylinder metals can be a good selection because it provides sufficient strength, ductility and keeps the manufacturing cost moderate. Here, the weight is not a significant factor, so we can select a low alloy steel (ASTM A414-Grade G). On the other hand when we fall our focus on aerospace engineering here the weight reduction (light weight) is more significant than the cost. So, for manufacturing aerospace pressure vessel aerospace engineer choice is composite material which provides light weight along with strength and ductility. So, a wise aeronautical engineer/aerospace engineer will always choice a polymer composite (Kevlar 49 aramid fibers) for designing an aerospace pressure vessel. Since, aerospace/aeronautical is an advanced branch of engineering where the term “safety” & “reliability” is more important than cost and so, the use of fiber reinforced polymer composite is taking its strong position in this field very rapidly. When we make unique combination of safety, reliability, light weight, strength and efficiency then there is no alternative to this polymer reinforce composite because it is aerospace which requires a lot of care. Otherwise the consequences will be dangerous and drastic.

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