Global Journal of Researches in Engineering: D
Chemical Engineering
Volume 14 Issue 1 Version 1.0 Year 2014
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Advanced Composite Materials in Typical Aerospace Applications

By Sanjay Kumar Sardiwal, Md. Abdul Sami, B. V. Sai Anoop, Gudipudi Susmita, Lahari Vooturi & Syed Arshad Uddin

MLR Institute of Technology, India

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. The use of composites for primary structures such as fuselages and wings has grown significantly in transport aircraft. Apart from increased strength at lower weights, composites also meet fatigue and damage tolerance, gust alleviation, and low noise foot print requirements. This paper examines the challenges and advantages of using composites in airframe manufacture, as opposed to other alloys. It also looks at the ways and means to ensure that safety and durability are not compromised by the use of composites. The prime objective of this paper is to highlight the use of advanced composite materials in the field of aerospace and to encourage readers to understand and to write papers on such topics.

Keywords: composites, polymers, matrices, resins, sandwich structures.

GJRE-D Classification : FOR Code: 861301, 090102

ADVANCEDCOMPOSITEMATERIALSINTYPICALAEROSPACEAPPLICATIONS

Advanced Composite Materials in Typical Aerospace Applications

Sanjay Kumar Sardiwal [α], Md. Abdul Sami [σ], B. V. Sai Anoop [ρ], Gudipudi Susmita [Ѡ], Lahari Vooturi [¥] & Syed Arshad Uddin [§]

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. The use of composites for primary structures such as fuselages and wings has grown significantly in transport aircraft. Apart from increased strength at lower weights, composites also meet fatigue and damage tolerance, gust alleviation, and low noise foot print requirements. This paper examines the challenges and advantages of using composites in airframe manufacture, as opposed to other alloys. It also looks at the ways and means to ensure that safety and durability are not compromised by the use of composites. The prime objective of this paper is to highlight the use of advanced composite materials in the field of aerospace and to encourage readers to understand and to write papers on such topics.

Keywords: composites, polymers, matrices, resins, sandwich structures.

I. Introduction

The need for the highly effective and efficient material which should be concerned with the ecology – concerned world of finite resources has led advanced composites to be one of most important materials in the high technology revolution in the world today. As we all know if the demand increases, the availability should also be increasing. The increased availability of these light, stiff and strong materials has made it possible to achieve a number of milestones in Aerospace technology. Metallurgists and designers have advantageously used these materials in the construction of modern fuel efficient aircraft, satellites, missiles, launchers and other space vehicles.

a) What are composites?

They are a blend of two or more materials and/or technologies brought together to produce an item giving specific characteristics for a particular application. The term composite is often used both in the modern context of Fibre 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 limitations in other properties. 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 materials which is light weight, stiff, strong and tough.

Author α σ ρ Ѡ ¥: Department of Aeronautical Engineering, MLR Institute of Technology, Hyderabad.
e-mail: sanjay.sardiwal33@gmail.com
Author §: Department of Aeronautical Engineering, Malla Reddy College of Engineering and Technology, Hyderabad.

b) Why Aerospace?

When it comes to safety and security the aerospace is one sector which needs a word "super" to be prefixed with these words "safety" and "security". 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. What if this happens in an airplane? The picture shown below will speak to you better.

Figure 1 : Fuselage damage to Aloha Airlines Flight 243, April 1988

II. Components of Advanced Polymer Composites

Advanced polymer composites generally contain reinforcing fibres in the form of continuous filamentary tows or fabrics and properly formulated polymetric 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.

a) Fibres

Fibres are widely used as reinforcements. Amongst the fibres available, glass, aramid and carbon fibres are in extensive use, although boron or other exotic fibres 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 fibres are given in tables 1 to 5.

Table 1 : Typical Properties of Glass Fibres

Properties	'E' glass	'R' glass	'D' glass
Density g/cc	2.60	2.55	2.16
Tensile strength, MPa	3400	4400	2500
Tensile modulus, GPa	73	86	55
Elongation at break, %	4.5	5.2	4.5
Filament diameter, μ	3-14	3-24	3-14

Table 2 : Typical Properties of Aramid Fibres (1)

Properties	Kevlar 49	Kevlar 149
Density g/cc	1.38	1.41
Tensile strength, MPa	3620	3447
Tensile modulus, GPa	127	175
Elongation at break, %	1.85	2.9

Table 3 : Properties of High Tensile Carbon Fibres (2)

Properties	T300	T400	T800	T1000
Density g/cc	1.75	1.80	1.81	1.82
Tensile strength, MPa	3528	4412	5588	7060
Tensile modulus, GPa	230	250	294	294
Elongation at break, %	1.50	1.80	1.90	2.4
Filament diameter, μ	7.0	6.8	5.2	5.3
Precursor	PAN			

Table 4 : Properties of High Modulus Carbon Fibres

Properties	M 30	M 40	M50
Density g/cc	1.7	1.81	1.91
Tensile strength, MPa	2920	2744	2450
Tensile modulus, GPa	294	392	490
Elongation at break, %	1.3	0.6	0.5
Filament diameter, μ	6.3	6.5	6.3
Precursor	PAN		

Table 5 : Properties of High Modulus High Strain Carbon Fibres

Properties	M 35J	M 40J	M 46J	M 55J
Density g/cc	1.75	1.77	1.84	1.91
Tensile strength, MPa	5000	4410	4210	2450
Tensile modulus, GPa	343	384	440	490
Elongation at break, %	1.6	1.2	1.0	0.5
Filament diameter, μ	5.2	5.2	5.1	6.3
Precursor	PAN			

It is evident that over the years substantial development has taken place in carbon fibre development work. Initially the trend was that the higher the modulli the lower the strengths (table 4). with improved precursor, method of graphitization and other parameters the production of fibres with higher strain was achieved and this has resulted in the availability of fibres with excellent mechanical properties.

b) Matrix

Matrices are essential ingredients to embed fibres and provide a supporting medium for them. It is the ability of the matrix to transfer stresses which determines the degree of realization of mechanical properties of fibres and final performance of the resultant composites. Stress-strain behavior and adhesion properties are important properties are important criteria which control the ability of the matrix to transfer stresses. A lot of research is being carried out on the basic understanding of the relationship between properties and production of tough, strong and stiff and environment resistant composite structures. This has helped in the development of composites having acceptable properties.

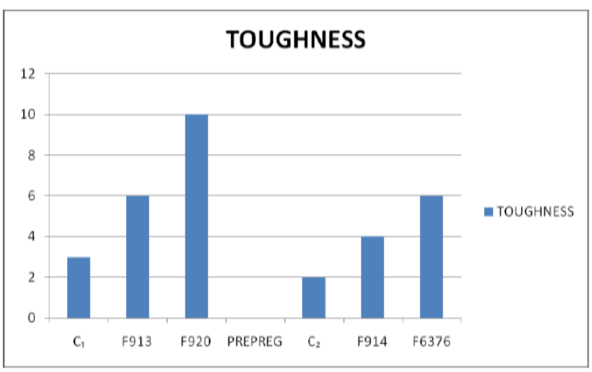
III. Properties

a) Toughness

In order to suit themselves for the aerospace applications it requires greater damage tolerance, high modulus, high strength and service temperatures of about 150ºC and above.

But there are these factors which affect this from happening.

In a brittle matrix full realization of mechanical properties of fibrous reinforcement are not achieved. Especially, impact properties of resultant composites are poor. Usually, the toughness achieved by flexibility of the polymer backbone or by external plasticity by using reactive dilute. By this method, although the impact strength is improved, the sacrifice of high temperature capability is inevitable. Another way of toughening matrix or adhesive systems is by inclusion of dispersed phase in the glassy matrix. Although the mechanism of toughening is not fully conclusive, it is believed to arise from stoppage or alteration of the mode of propagation of micro crack(s). Reacting with CTBN rubbers and alloying with thermoplastics thermosetting resins can be toughened. It is obvious that significant achievement has taken place in the toughening of epoxy based matrices. Composites made from these new- generation 175ºC – curing machines and recently developed high strain fibres, almost satisfying the requirement needed for a material to be used in aerospace application.



C_1: 120C curing epoxy based system not formulated for toughness

C_2: 175C curing system based on widely used MY 720 and DD

Figure 2 : comparison of toughness of carbon fiber composites based on toughened and untoughened epoxy system

b) Heat, Humidity and Chemical Resistance

Better maintenance of mechanical properties over a wide range of temperature is an essential for structural composites. Polymers with higher aromaticity tend to have higher T_g toughness and T_g often call for optimization. Resistance to hot and wet conditions and various solvents, and fire retardancy is also required. Composite products which are used for interior furnishing of civil aircrafts and surface vehicles need to meet stringent requirements of lower smoke generation and least toxicity under pyrolytic conditions. Phenolic resins are chosen as base matrix materials for making composites for such high heat and fire-safe applications.

c) Ease of Handling and Processing

Handling and processing characteristics are equally important. The resultant properties of finished composite items are dependent on how well the composite raw materials are manipulated and processed. Shelf life, tackiness and drapability are the important criteria for laying up, winding and stacking by shop floor operators. Specifications in respect of these are met by judicious selection of hardeners, modifying additives and other relevant considerations.

The technique of partial advancement of partial advancement of resin matrices is conventionally employed in the preparation of fibrous pre- impregnates which are subsequently used for fabrication of composite items by heat and pressure. The shelf life of such impregnates is limited and production of void- free cured composite items is sensitive to processing conditions with respect to heating rate, time of application and duration of pressure and cure temperature. Dynamic viscosities of two matrices with controlled flow and a widely used system based on MY 720 and DDS. A straight up simple cure cycle can be employed for Fibredux 913 (a trade mark of CIBA-GEIGY) and Fibredux 914 composites systems where as a dwelled complex cure cycle is necessary for MY 720/DDS system. It is evident that this cure cycle is difficult to monitor because one has to apply pressure when a particular viscosity is attained in order to avoid running away of resin its fluid state. A number of cure cycle can be employed for a matrix system with controlled viscosity and reactivity.

IV. Basic Polymers for Matrices

- *Epoxy Resins*

Epoxy resins are still the work- horse of advanced polymer composites today.

- *Phenolic Resins*

Mechanical properties are not good as that of epoxy resins. However, phenolics are employed for applications requiring better ablative properties and low smoke generation.

- *Bismaleimides*

The class of matrix materials has a higher T_g and acceptable mechanical properties including resistance to impact. A number of systems based on bismaleimide resins are accepted for commercial production. Metamid ™ 5292 A/B bismaleimeide system has a T_g of 270ºC and attractive mechanical properties. This system is based on 4, 4′

Bismaleimidodiphenylmethane and 0, 0′ Diallyl Bisphenol A.

a) Themoplastics

Engineering thermoplastics are undergoing extensive evaluation for their use as matrices. They have good mechanical and thermal properties. Because of their excellent fracture resistance thermoplastics are superior to thermosets with respect to the damage tolerance as reflected in residual compression strengths. Residual compression strengths after impact loading of PEEK and a few thermosets as matrices are compared in the figure 4. Other advantages are long storage life short moulding cycle and reprocessibility. Inspite of the above, lack of long term performance data is one of retarding factors for their extensive use on a commercial scale. Some of the important thermoplastics are Polyether ketones, polysulphides, polysulphones, and polyamides. And some of the suppliers are ICI, Dupont, Phillips, Amoco, Ciba-Geigy, rogers, NASA, General Electric.

b) Prepregs

Pre assembled and impregnated fibres and fabrics are known as prepregs. Thus are preferred by users in the aerospace industry as they have the following advantages:

i. They are supplied in ready to use form. This eliminates handling of solvents, hardeners, additives, heat resin and other chemicals
ii. Most proprietary prepegs are based on the state of the art matrix systems which are developed through extensive R&D efforts and offer the best properties with respect to toughness, environmental resistance and ease of processing to shop floor operators. These matrix systems are not available as commodity resins.
iii. Sophisticated equipment is needed for the production of quality prepegs with stringent specifications of resin and fibre weight tolerance and hence capital investment is high. this can be justified if a large volume is produced and supplied to many users.
iv. Handling of fine fibre tows for making continuous unidirectional prepegs needs skill and experience of the highest order, otherwise the reject rate could be high.

Several techniques are available for making prepegs. For high quality unidirectional (UD) prepegs, matrix film transfer and hot-melt impregnation process is adopted.

c) Surface treatment of carbon fibre

Bonds between matrices and carbon fibre, especially of high modulus carbon fibre, tend to be poor and not adequate for most applications. This has necessitated treatment of carbon fibre filaments to enhance interlaminar shear strength (ILSS) of cured composites. The treatment is based on oxidizing chemical agents. The treated fibres are given a polymeric coating before they are sent for prepegging.

V. Recent Development in Matrices

With the commercial production of high strain carbon fibres need for newer generation of polymeric matrices, having higher extensibility and greater fracture toughness, but without sacrificing high temeperature capability has become imperative. As a result, R & D oriented manufacturers of prepegs have undertaken the task of developing matrices with the following requirements:

- Good translation of properties with new high strain carbon fibres
- Improved fracture toughness and impact performance
- Straight – up cure cycle.
- Good hot wet properties upto 150º and beyond.
- Controlled flow and reactivity built in matrices for ease of processing including preassembly before curing.

To meet the above requirements a number of matrices have been developed. Other proprietary product with similar characteristics may be available. Composite properties of these matrices are given in the table drawn below.

Matrix and fibre	0º LAMINATE PROPERTIES			
	Tensile strength	Tensile modulus	ILSS,MPa	G*IC* (Toughness) JM-2
F914 + T300	1650	135	118	350
F6376 + 1M6	2696	172	131	
F 924 + T 800	2610	169	130	666
Vx M18 + M 40JB	2370	221	84	
Vx M18 + M 55J	1850	320	65	

a) Sandwich Structures

Sandwich structures, consisting of profiled or rectangular honeycomb or structural foam cores, bonded on either side to skins of metallic sheets or FRP laminates, are used in applications where extremes of lightness and stiffness are predominant requirements.

The last sentenced could otherwise be used to describe "AEROSPACE APPLICATIONS".

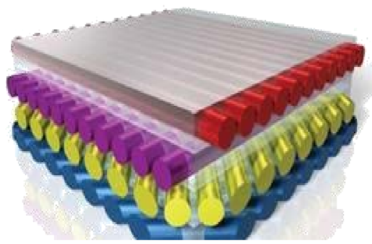


Figure 3 : A graphic indicating how the layers are arranged

The above picture otherwise depicts the way in which the different layers are arranged in the form of a pile.

b) Processing

A number of methods are available for processing advanced composites. Some of them are compression moulding, wet and dry winding, Resin Transfer Moulding (RTM) pultrution and bag moulding (pressure bag, vacuum bag and autoclave). In aerospace industry autoclave processing is used preferentially. For making flat sandwich panels press moulding is the most efficient and economical method which is widely adopted. Filament winding is used for making cylindrical and spherical structures. For mass production, RTM and pulstrution techniques are employed.

c) Applications of Composites - Justification

Applications of advanced composites, especially carbon fibre containing composites are justified on the following grounds:

- Combination of light weight, high modulus and superior strength.
- Good fatigue and corrosion resistance.
- Unique design possibility including ease of fabrication of complicated structures
- Reduced parts count and hence low inventory and assembly time
- Low energy requirements of production and Labour cost of processing

Advanced composites excel over their metallic counter parts, especially in specific modulus and strength. Since these criteria have a significant influence and fuel consumption of aerospace vehicles. Advanced composites are being extensively and justifiably used in aerospace areas rather than in other industries. The cost factor is a detterent for the latter.

VI. Aerospace Applications

The last yet very important topic in my paper is this particular topic. Applications of these composites in aerospace engineering. Being an aerospace engineer I must be giving an layout of a/c (it's not air conditioner this is how we abbreviate aircraft) without possibilities of amalgamating the above explanations given regarding composites.

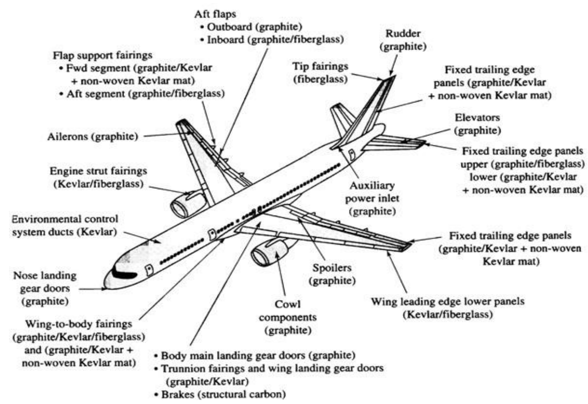


Figure 4 : Aircraft's layout

a) Aircrafts and other air breathing vehicles which can be airborne

Though the advanced composites in the construction of aircraft and helicopters, weight savings of 20-30% are achieved as compared to conventional materials. Fairings, landing gears, engine cowls, rudder, fin boxes, doors, floor boards and many other interior gadgets are made of advanced composites in combination with metallic and non metallic honey comb cores and metals. The recently launched prototype of Advanced Light Helicopter (ALH) is said to have as much as 60% of the surface area made up of composite components including advanced fibre components and metal sandwich structures.

b) Space

Two factors, high specific modulus and strength, and dimensional stability during large changes in temperature in space make composites the material of choice in space applications. Examples include the graphite/epoxy-honeycomb payload bay doors in the space shuttle. Weight savings over conventional metal alloys translate to higher payloads which cost as much as \$1000/lb (\$2280/kg). also, for the space shuttles remote manipulator arm, which deploys and retrieves payloads, graphite/epoxy was chosen primary for weight savings and for small mechanical and thermal deflections. Antenna ribs and struts in satellite systems use graphite/epoxy for their high specific stiffness and its ability to meet the dimensional stability requirements due to large temperature excursions in space. Remember *"aerodynamic heating"* during reentry should also be taken into concern.

c) Rocket and Missiles

Rocket motor cases and liners are made using composites of carbon, aramid and glass. Formulated epoxies, phenolics and polyimide materials are being

Global Journal of Researches in Engineering (D) Volume XIV Issue I Version I Year 2014

used. Carbon – carbon composites are used for re-entry nose tips and heat shields. These applications, which require a lower ablation rate, higher bulk density and superior mechanical strength, are possible with carbon-carbon composites compared to monolithic graphite. Carbon–carbon composite items are successfully made from 3-D fabrics followed by densification process.

VII. Conclusion

The material selection plays a very important role in the engineering. Almost everyone knows the story of *"TITANIC"*. I am not discussing about the movie but the engineering behind the failure of the ship. Similarly there is one area which a lot of concentration in everything right from material selection to fabrication. Yes your thought is correct! it is Aerospace sector which needs a lot of care. Otherwise the consequences will be drastic.

In our country, although a lot of aerospace programmes have started using advanced composites, other industries are not aware of the development in this ever growing area of composite technology. This is due to lack of access to this technology and non implementation of the locally manufacturing prepegs at a reasonable cost. It is hoped that above the shortcomings will be overcome in the mere future!! Let the aerospace sector grow further by making use of this technology more and more.

References Références Referencias

1. B. D. Agarwal, L. J. Broutman and K. Chandrashekhara, 2006 2006 *"ANALYSIS AND PERFORMANCE OF FIBER COMPOSITES, Third Edition,"* John Wiley & sons, New York, 1980.
2. Gupta. L, Advanced Composite Materials, Himalayan Books, New Delhi, 1998.
3. Jones, R.M. Mechanics of Composite Materials, Mc Graw Hill, Kogakusha, ltd. Tokyo.
4. Dr. P. Mitra *"Advanced Polymer Composites with special reference to Carbon Fibre Reinforced Polymer (CFRP)".*
5. Autar K. Kaw "*Mechanics of Composite Materials*".
6. R.Velmurugan *"Composite Materials for Aerospace Applications".*
7. Tim Edwards "C*omposite Materials Revolutionize Aerospace Engineering".*