ПРОИЗВОДСТВО УЛУЧШЕННЫХ МАТЕРИАЛОВ ДЛЯ АЭРОКОСМИЧЕСКОГО ПРИМЕНЕНИЯ. ОБЗОР

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Аннотация: *в связи с развитием в авиации, некоторые материалы уже протестированы и использованы для улучшения аэродинамики, в то же время вызывая уменьшение цены производства летательных аппаратов. Такие металлы, как алюминий и титан, играли важные роли в строительстве в авиационной промышленности. Для того чтобы достигнуть легковесных и высокопрочных требований авиационной отрасли, различные материалы разрабатываются. В этой работе мы дали обзор различных композитных материалов, в том числе гибридов и керамическо-матричных композитов (CMC), а также некоторые из важных методов производства композитов. Объединение материалов различных свойств приводит к появлению новых материалов, обладающих механическими свойствами, которые лучше свойств обычных металлов, применяемых в авиации. Они обеспечивают двойственность с точки зрения улучшенных влияний на работу летательных аппаратов и их долговечности. Компоненты этих композитов расположены таким образом, чтобы дать максимальную прочность и уменьшить вероятность непредвиденной деформации в результате напряженно-деформированного состояния части летательного аппарата, изготовленной этими композитами. Композиты предпочтительнее благодаря их прочности, высокому пределу прочности, высокому сопротивлению деформации и высокой теплостойкости. Преимущества композитов превышают их недостатки намного. Это дает возможность нового исследования и развития для лучшей производительности воздушных судов. В зависимости от конкретного применения этих материалов, различные виды производительных методов были применены на основании формы и назначения производимого элемента.*

Ключевые слова: *композит, аэрокосмический, волокно, ориентация, матрица, жесткость, эпоксидная смола.*

MANUFACTURING ADVANCED MATERIALS FOR AEROSPACE APPLICATION. AN OVERVIEW

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Abstract: *with the advent of aviation, several materials have been tested and used to improve the aerodynamics while reducing manufacturing cost of flying vehicles. Metals such as aluminum and titanium have played vital roles in construction in the aerospace industry. In order to meet the lightweight and high-strength demands of the aerospace industry, different materials are being developed. In this work, I have given an overview on composite materials including hybrids and ceramic matrix composites(CMC) and some of the important methods of manufacturing composites. The combining of materials of different properties produces new materials that are of better mechanical properties over common metals used in aerospace engineering. They provide duality in terms of better effects on the overall functioning of flight vehicles and durability. The components of these composites are arranged in a manner to give maximum strength and reduce the probability of unforeseen deformation as a result of the stress and strain of the part of the aircraft it is used to manufacture. Composites are preferred because of their toughness, high tensile strength and failure to strain easily and posses high thermal resistance. The advantages of* *composites outweigh their disadvantages by a respectable margin. This gives rise to a new study and development for better performance of aircrafts. Depending on the specific applications of these materials, different kinds of manufacturing methods have been utilized based on the shape and purpose of the element being manufactured.*

***Keywords**: composite, aerospace, fiber, orientation, matrix, stiffness, epoxy.*

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1. Introduction

Recently, composites such as the Carbon Fiber Reinforced Plastic (CFRP) have taken over traditional metals that once dominated the aerospace industry (even the automobile industry). About half a century ago, a typical airplane consisted of about 70 percent of pure duralumin. It was used because it was considered inexpensive and lightweight. Times have changed and most of the aircrafts we have around are only made up of about 20 percent pure aluminum. The structural components of the interior and paneling are currently made of reinforced carbon fibers called composites. In the construction of aircrafts, there is a simultaneous push for lightweight and high temperature resistance in order to increase the range, payload, maneuverability, and fuel efficiency, bringing new or previously impractical-to-machine metals into the aerospace material mix. The performance of composites depends not only on the choice of the matrix material and the fiber, but also the manufacturing processes by which they are made.

2. The definition of Composites

The term composite is common in the field of material science but what actually does it mean? The science of combining several materials to produce a new material with advanced properties is not of recent origin. The first use of composites goes back to 1500 B.C. when early Egyptian and Mesopotamian settlers used a mixture of mud and straw to build strong and durable housing.

So basically, if two or more chemically different materials are joined with interfaces which can be seen physically, the product is called a composite. This is done in order to obtain the better qualities from these materials. With regards to carbon fibers, they are strong and stiff but cannot be used in the design of an aircraft. This is because carbon is very brittle. Considering plastic (epoxy), they are soft and resistant to corrosion. So, if these two materials are combined together, the resultant product is called Carbon Fiber Reinforced Polymer(CFRP). If glass fibers are used instead of carbon, it is called Glass Fiber Reinforced Polymer(GFRP) or fiberglass. Apart from CFRC and GFRC, there are other forms of composites, such as Quartz Fiber Reinforced Composites(QFRC). Metallic alloys are not called composites because their composition is not visual but that of composites can be seen.

2.1. Fiber Orientation

A typical composite structure consist of fibers arranged in different directions. These directions are called orientations. There is a common axis to refer to, X-Y axis as shown in fig1. The angle between the axis is theta. When theta is zero, all fibers run vertically. This is called zero ply. When theta goes to 90, the fibers are going horizontally and when theta equals 45, the fibers run diagonally.

In designing high performance elements like in the aerospace industry, the load requirements determine the fiber orientations. Fibers run in different directions in a composite material to make it stronger. For actual applications, a typical composite structure has 0,90, -/+ 45 orientations. 0 is the strongest in the vertical direction and 90 in the horizontal direction. For best shear properties, 45 orientation is used and - 45 is used to balance the laminate. These orientations can be seen in fig3. (cite my paper).

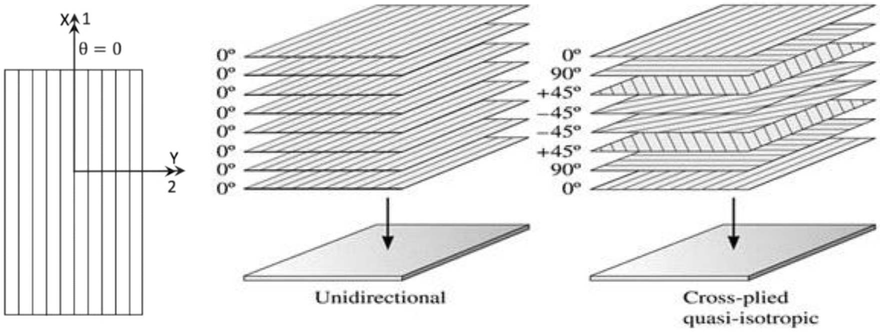


Fig. 1. Fiber Orientation

3.0. Why composites?

Outlined below are a few major reasons why we use or study composite technology:

- lightweight

- high strength
- strength to weight ratio
- thermal resistance
- minimal fatigue
- corrosion resistance
- design flexibility

Composites are designed in order to increase the strength, stiffness and also reduce the weight, improve the fatigue life and thermal expansion and also the high temperature resistance of aerospace structures. In designing of aircraft wings, if the stiffness is not enough, definitely there would be a large deformation. For example, if there are two airplanes with wings made of carbon epoxy and glass epoxy respectively, the wings of the latter will deform faster than the former which is not desirable. This is because glass epoxies are less stiff than carbon epoxies. The stiffness of the materials is a very important parameter. When designing high performance structures like flight vehicles, the stiffness and strength of the materials must be put into consideration. The mass of these materials is also important. Materials with high stiffness but with low density are preferred and that is why composites materials are favoured over traditional metals like aluminum and titanium. Carbon epoxy only weighs about 60% of aluminum. Also, composites don't fatigue compared to metals. For carbon epoxy with about ten million cycles of loading, 80% of the strengths can be recovered. In contrast to composites, metals like aluminium have endurance limit of about 40%.

Thermal expansion-the ideal case for space vehicles. They are exposed to different kind of radiations, including thermal radiations. Composites don't expand under temperature and also doesn't contract under cold. They are said to be thermally stable. Carbon epoxy is ideal in the design of space vehicles.

In corrosive environments, most metals change into powder. So, composites are preferred over metals. Aluminium airplanes are so sensitive to corrosion, like salt water under the stress environment. Composites don't corrode and that’s a great advantage for them. In design of aerospace structures, these properties of composites answer the question of why engineers are inclined to them. Due to their ability to be molded into complex shapes, composites are renowned for their design flexibility. In fig.2, an aircraft fairing panel has been molded for an aircraft wheel.

Fig. 2. A molded aircraft fairing panel using CFRP

4.0. Fiber metal laminates

Fiber metal laminates (FMLs) are hybrid composite structures based on thin sheets of metal alloys and plies of fiber reinforced polymeric materials. The fiber/metal composite technology combines the advantages of metallic materials and fiber reinforced matrix systems. Metals for instance, have a high bearing strength and impact resistance and are easy to repair, while full composites have excellent fatigue characteristics and high strength and stiffness. The fatigue and corrosion characteristics of metals and the low bearing strength, impact resistance and reparability of composites can be overcome by the combination. These material systems are created by bonding composite laminates to metal laminates. Adhesives are used in joining the different layers together.

Adhesive bonding process has been used in the manufacture of aircraft structures and components for 30–40 years. Bonding the laminates in aerospace and aeronautical industries (F-18 bonded wings) with adhesives offers many advantages over conventional mechanical fasteners: lower structural weight, lower fabrication cost, and improved damage tolerance. Light weight sandwich construction and structural bonded joints form a major proportion of modern aircraft. For example, structural adhesive bonding is mainly used for attaching stringers and/ or tear straps to the fuselage and wing skins, to stiffen the structures against buckling. Bonded structures have been shown to be far more fatigue resistant than equivalent mechanically fastened structures and when designed correctly, can sustain higher loads than equivalent mechanically fastened joints. The most commercially available FMLs are Aramid Reinforced Aluminium Laminate(ARALL) based of aramid fibers, Glass Reinforced Aluminium Laminate(GLARE) based on high strength glass fibers, and Carbon Reinforced Aluminium Laminate(CARALL) based on carbon fibers.

ARALL laminates are made of high strength aramid fibersburied in a structural epoxy adhesive sandwiched between multiple layers of thin aluminium alloy sheets. Combination of high strength metals (aluminium layers) and strong fibers (aramid layers) generates a new composite material with special properties. ARALL laminates offer many advantages such as high strength and excellent fatigue properties. The advantages of aluminium alloys, namely lower cost, easy machining, forming, and mechanical fastening abilities, as well as substantial ductility are retained. In the ARALL concept, unidirectional fiber orientation is used. This concept is very tolerant of material inconsistencies. The fiber orientation is chosen in the direction of the main load. The laminates are designed in such a manner that the fibers do not fail, when fatigue cracks develop. That means they remain intact and prevent crack propagation. ARALL laminates are useful especially for fatigue dominated structural parts, such as the lower wing skin and the pressurized fuselage cabin of an aircraft. It has been used for the lower wing skin panels of the former Fokker 27 aircraft and the cargo door of the Boeing C-17.

GLARE laminates consist of alternating layers of unidirectional reinforced glass fibers and high strength aluminium alloy sheets. The main differentiation of GLARE compared to ARALL is that GLARE consists of glass fibers instead of aramid fibers. This diversity gives superior properties to GLARE laminates. Table1. gives information about the advantages and disadvantages FML fibers (Aramid and Glass). Furthermore, the fracture toughness and the durability in terms of water absorption of aramid fibers of different standards and that of glass were compared using CES EduPark2016 as seen in fig. 3.

Table1. Advantages and Disadvantages of FML fibers

Fiber	**Advantage**	**Disadvantage**	**FML**
Aramid	1.Outstanding toughness 2.Excellent fatigue resistance in both tensile and flexural fatigue loading 3.High young modulus 4.Low weight	1.Weak in bending, buckling, compression loading and transverse tension 2.Absorb moisture 3.Do not form strong bonds with other materials such as composite matrices	ARALL
Glass	1.High tensile strength 2.High failure strain 3.Do not absorb water	1.High weight 2.Low stiffness	GLARE

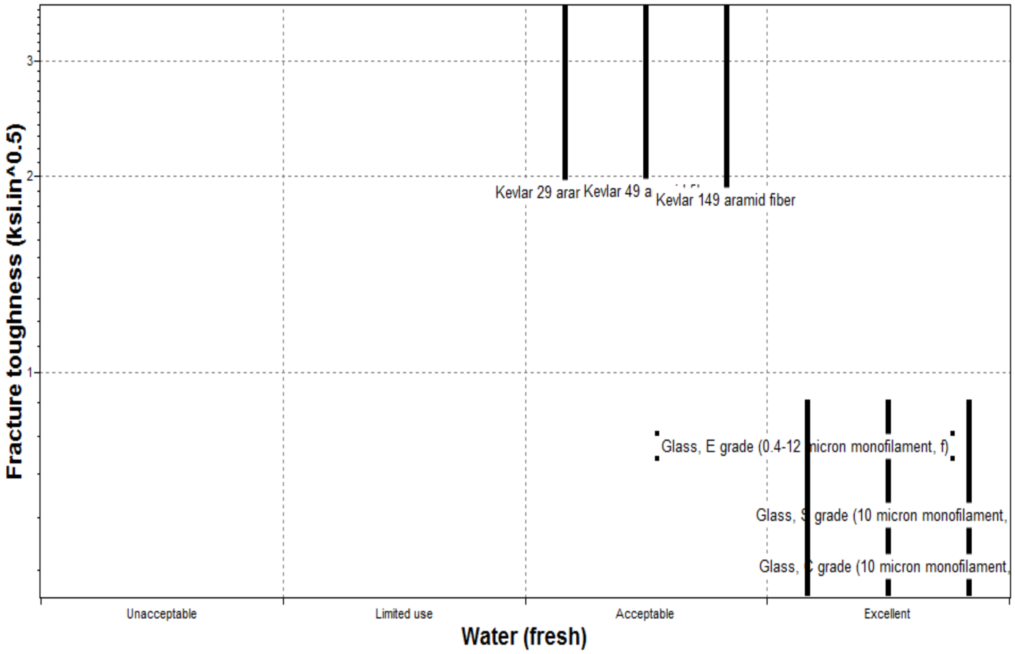
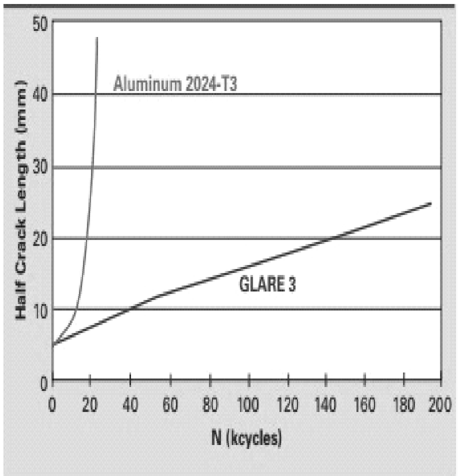


Fig. 3. Fracture Toughness and Water Absorption Properties of Aramid and Glass Fibers

The specific stiffness and strength in the fiber direction of GLARE are enhanced over the high strength aluminium alloy used for the metal layers, which significantly contributes to weight savings in the designs of tension-dominated structural components. Aforementioned fiber bridging mechanism impedes the growth and propagation of cracks in the aluminium-alloy layers under tensile fatigue loading conditions. The glass fibers in GLARE compared to ARALL are more adhesive. Moreover, glass fibers are much more resistant to compression loading. As a consequence, fiber failure in the glass fibers has rarely been observed during in fatigue load. Other advantages of GLARE over ARALL are its higher tensile and compressive strength, better impact behavior and better residual strength. Better adhesion between glass fiber and resin makes GLARE laminates with fibers build up in two directions is possible.

In comparison with aluminium alloys like 2024-T3 aluminiumoutstanding fatigue resistance and impact properties, impressive mechanical properties like fracture toughness, thermal resistance, and lightning strike resistance are some of GLARE laminates many desirable attributes.



Property	GLARE	2024-T3 Aluminum
Weight	0.7 - 0.9	1
Strength	1 - 2	1
Fatigue	3 - 100	1
Damage Tolerance	1 - 2	1
Impact Blast Resistance	2 - 10	1
Flame Resistance	5 - 50	1
Lightning Strike	1.5 - 2.5	1
Thermal Insulation	100 - 150	1
Corrosion Resistance	2 - 10	1
Reparability	1+	1
Maintenance	1+	1

Fig. 4. Properties of GLARE compared to 2024-T3 aluminium

Recently, GLARE is used in the main fuselage skin and the leading edges of the horizontal and vertical tail planes of new, high capacity Airbus A380.The application is a consequence of the excellent impact resistance of the

FML concept utilizing the high strength glass fibers with strain rate effect. With excellent impact characteristics, GLARE is being evaluated for use as cockpit crown, forward bulkheads, the leading edge and the flame-resistant capability of GLARE makes it suitable for flame sensitive areas such as; fire walls and cargo-liners.

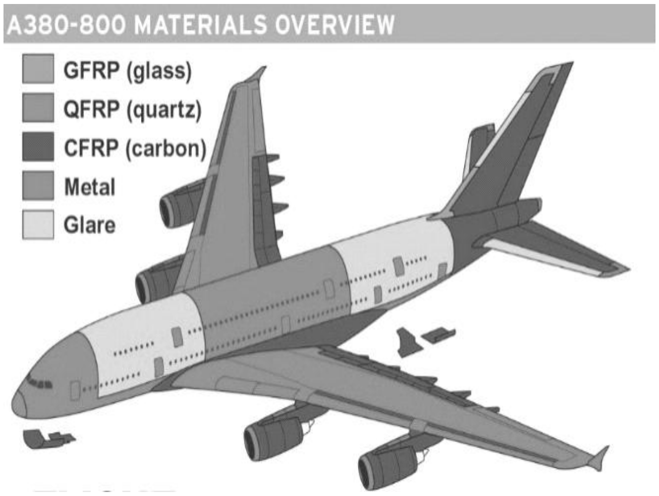


Fig. 5. Airbus A380

CARALL: As outlined in table1 Aramid fibers gives good specific strength and modulus, high impact resistance and outstanding toughness to ARALL laminates. However, their poor compressive strength is a capital limitation for these hybrid composites. As a result of that, CARALL laminates was developed as an improvement of ARALL laminates. They use carbon/epoxy prepregs instead of aramid/ epoxy prepregs. The high stiffness of carbon fibers allows for efficient crack bridging and therefore very low crack growth rates. The combination of high stiffness and strength with good impact properties gives CARALL laminates a great advantage for space applications. They are impact absorbers for helicopter struts and aircraft seats.

5.0. Ceramic Matrix Composites

Ceramic matrix composite(CMC) are made of ceramic fibers embedded in a ceramic matrix. They are lightweight and have high thermal resistance. They are capable of withstanding temperatures over 1500C which traditional metals like nickel cannotendure. The future of CMCs relies basically in aircraft turbine engines. If certain components that are exposed to extensive heating such as the turbine disc, combustor linear and turbine airfoils are made of CMCs, the engines will help lower fuel burn and emissions and also reduce the total weight of the aircraft. Also, today's metal parts require extensive cooling air and part of this is taken from the airflow in the engines and reduces efficiency. In contrast to metals, CMCs can operate with very little or no cooling and this increases the efficiency of the engines. CMCs also have one-third the weight of nickel.

CMCs are being in the production of the CFM's LEAP turbofan engine which powers the Airbus A320neo (2016) and will power the new Boeing 737max.

Using the CES EduPark, the maximum service temperature and density of a typical CMC fiber (Silicon Carbide fiber) and that of nickel alloys used for the combustion chamber of the gas turbine engine were compared. HAYNES230, HASTELLOY X and INCONEL 671, the most widely used alloys of Nickel for the combustion chamber were selected. As seen in fig.6, the silicon carbide fibers as compared to the nickel alloys will operate at a higher service temperature and are lighter as well.

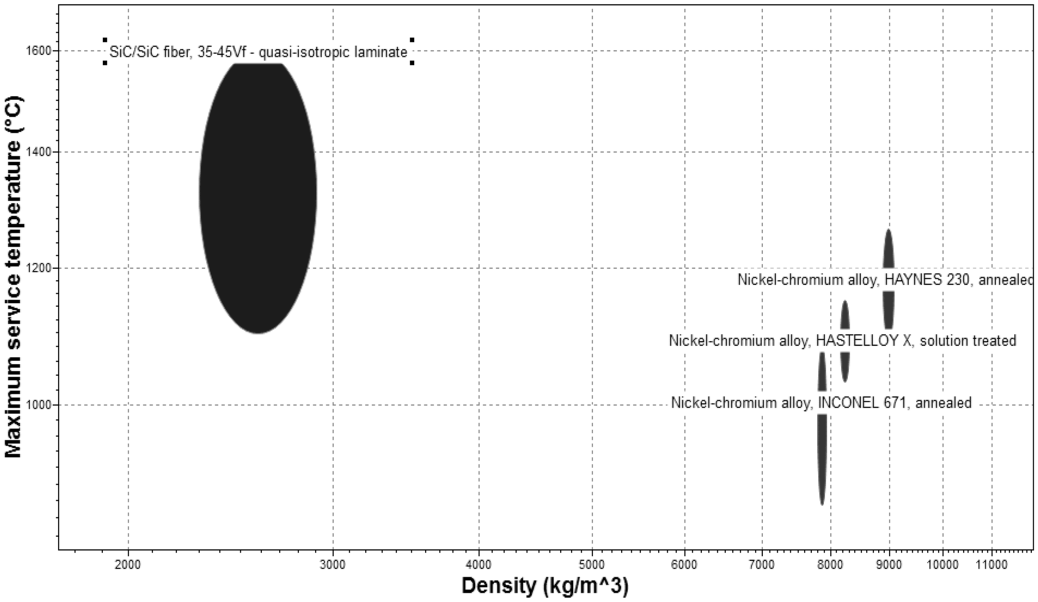
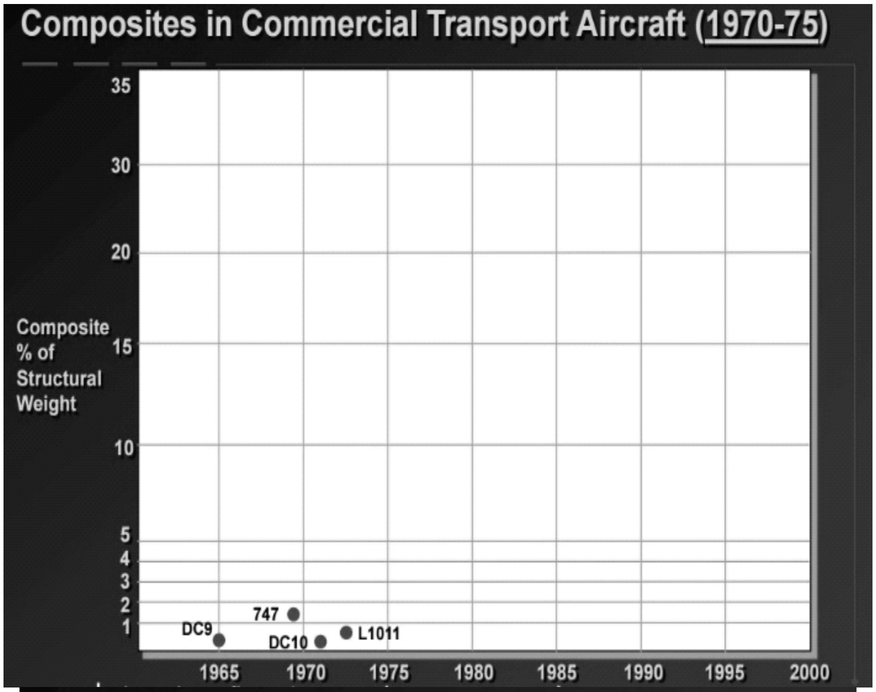


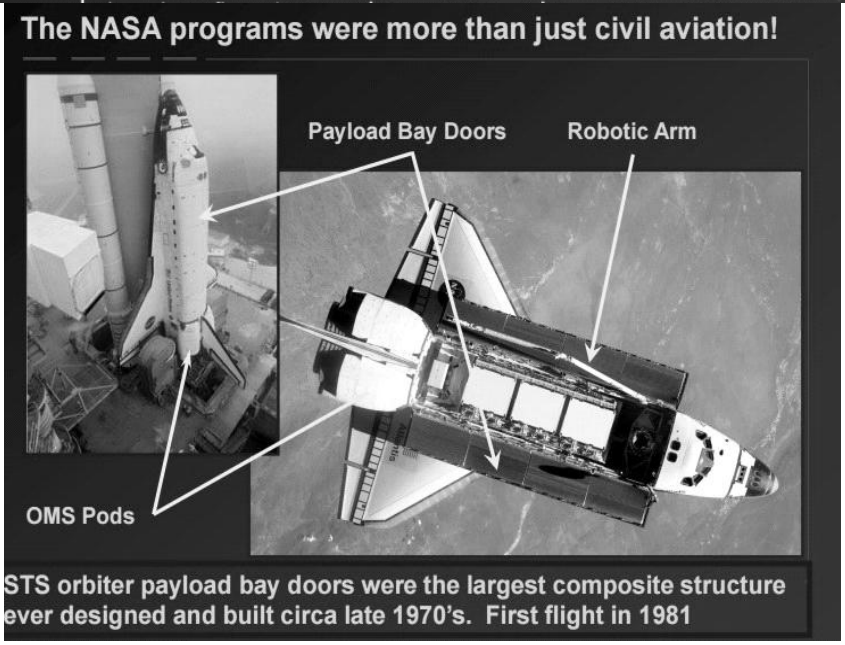
Fig. 6. Comparing the Maximum service temperature and density of CMC (SiC/SiC fiber) and Nickel alloys

6.0. Chronological Use of Composites

The gradual demand for composites over the years is explained in the following charts:



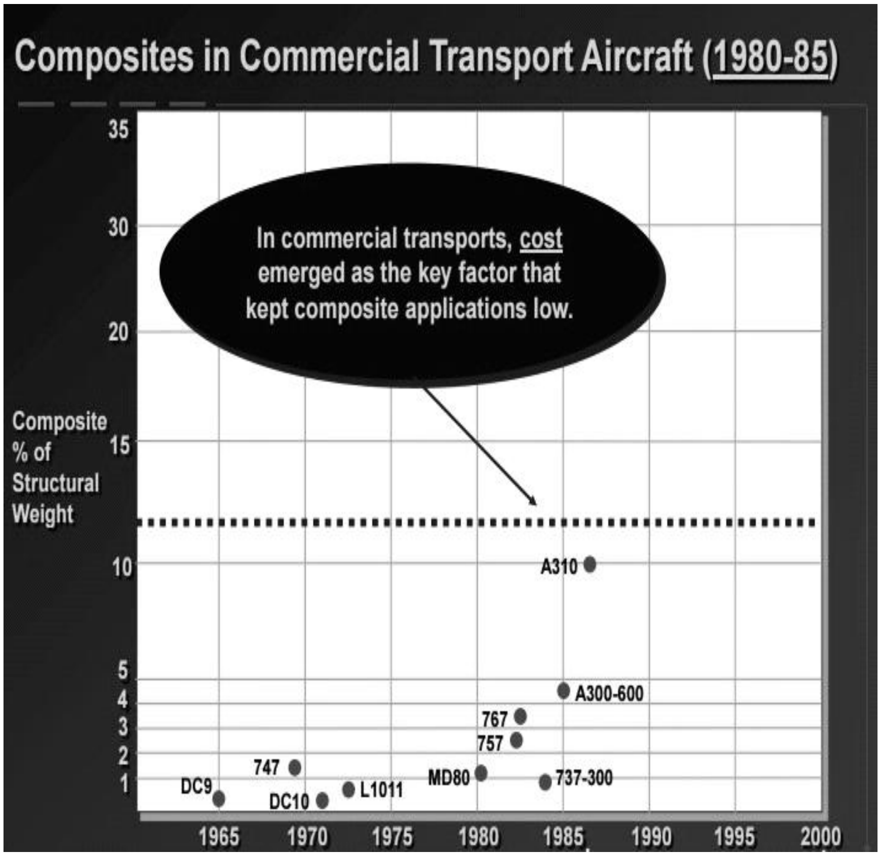
Composites in Commercial Transport Aircraft (1970-75)



The NASA programs were more than just civil aviation!

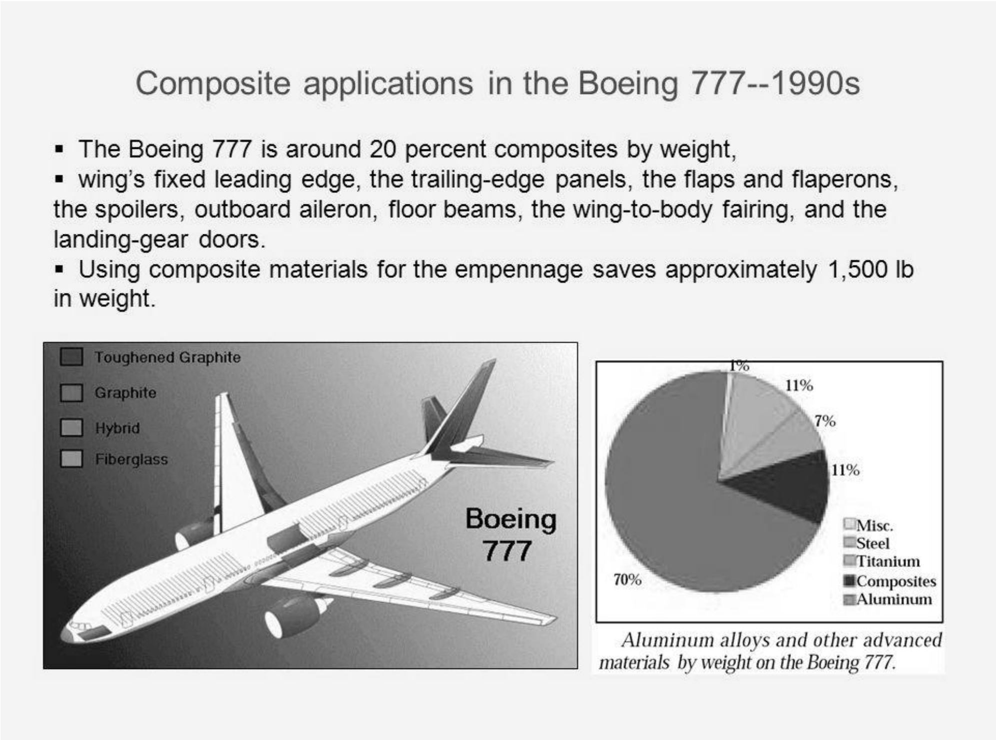
STS orbiter payload bay doors were the largest composite structure ever designed and built circa late 1970's. First flight in 1981

Fig. 7. Use of composites in the early 70s including NASA's STS orbiter


Composites in Commercial Transport Aircraft (1980-85)

In commercial transports, cost emerged as the key factor that kept composite applications low.

Fig. 8. In the 1980s, there was a significant increase in the number of aircrafts that used composites. A310 for example, has about 10% of its structural component made of composites


Composite applications in the Boeing 777--1990s

- The Boeing 777 is around 20 percent composites by weight,
- wing's fixed leading edge, the trailing-edge panels, the flaps and flaperons, the spoilers, outboard aileron, floor beams, the wing-to-body fairing, and the landing-gear doors.
- Using composite materials for the empennage saves approximately 1,500 lb in weight.

Aluminum alloys and other advanced materials by weight on the Boeing 777.

Fig. 9. Boeing 777 in the 1990s used composites for about 12% of its airframe

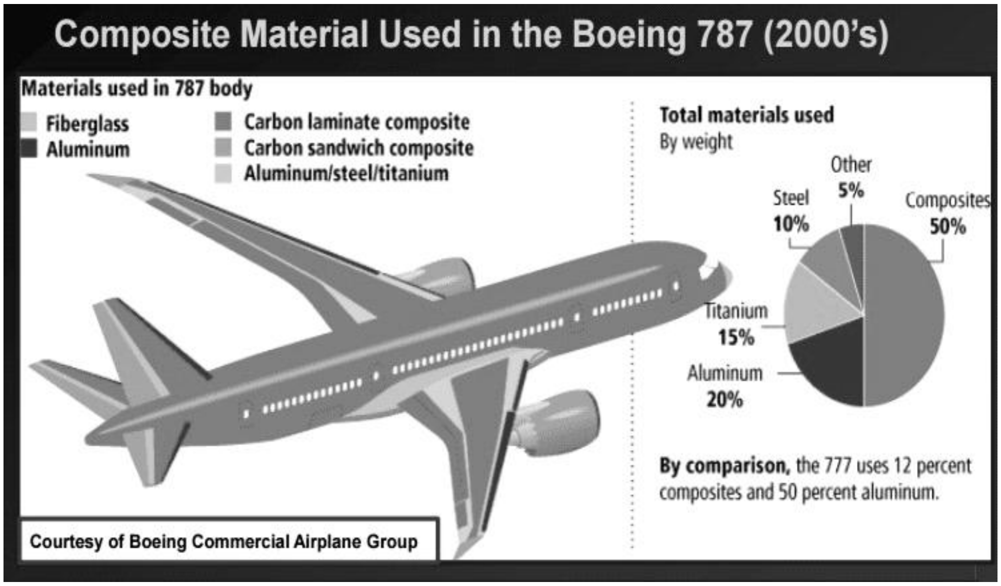


Fig. 10. 50% composite airframe for the Boeing 787

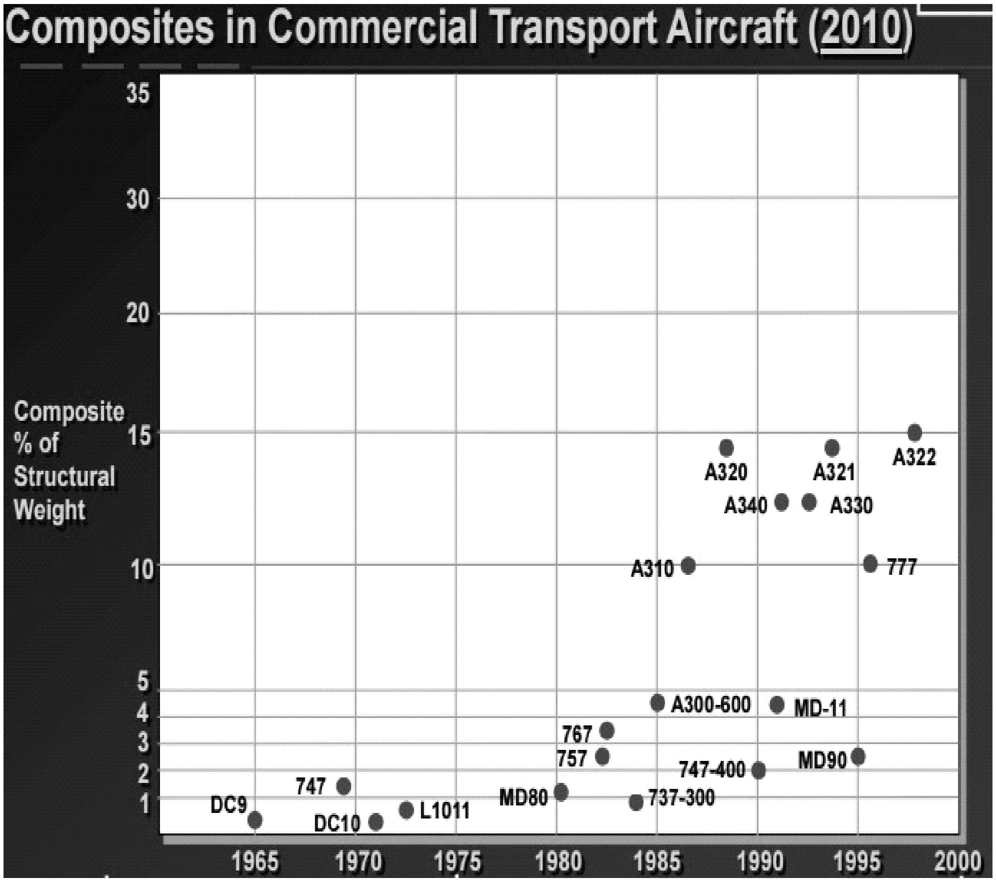


Fig. 11. Post 2000s

7.0. Composite Manufacturing Methods

There are various manufacturing methods used when fabricating elements of aircrafts or automobiles made of composite material. Below, a few of the main methods have been highlighted:

- manual lay-up
- automated lay-up

- pultrusion
- resin transfer molding

7.1. Manual Lay-up

This involves the cutting of reinforcement material into size using hand or power operated machines. The manual lay-up method is the most common and the least expensive because it requires very few equipment. The fibers are placed in a mold using the hand and the resin is applied using a roller or a brush. One of the disadvantages of this method is warping. If fiber reinforcements are not placed appropriately (wrong orientation), there is a distortion in the final material gotten after curing. To solve the problem of warping, the warped material is compensated by placing fibers in the opposite direction.

Fig. 12. A manually cut Carbon being covered with a resin material before curing at the Center of Composite Technology, Kazan, Russia

Fig. 13. A warped CFRP

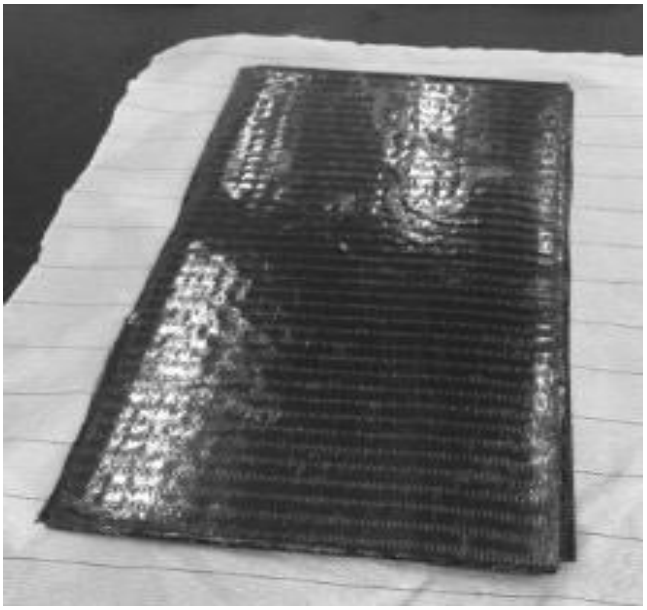


Fig. 14. Warped CFRP in b above being compensated with fibers in the opposite direction

7.2. Automated Lay-up

To fasten the manual lay-up method, an automated complex or CNC machines are used. The automated complex in fig6 below carries out prepreg tape laying, prepreg fiber placement, braiding (single cross-section or multi-axial) and stitching of fibers.

Fig. 15. An automated complex at CCT-KAI, Kazan, Russia

7.3. Pultrusion

Pultrusion is a manufacturing process used in making lengths of composite material with a constant cross-section. Examples of pultruded materials include beams used in aircraft fuselage, panels, aircraft deck floors.

The process involves pulling continuous reinforced fibers through a resin bath, followed by a preforming system, and directly into a heated die where the resin undergoes polymerization. There are different kinds of resins used in pultrusion, a few include polyester, polyurethane, and epoxy.

Flexibility in design and the various material mix up or combinations are the main pluses of pultrusion. There are unlimited structural possibilities.

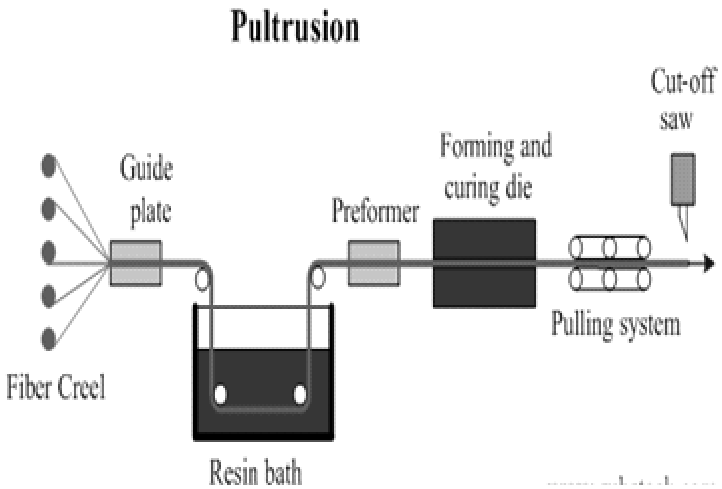


Fig. 16. The Pultrusion Process

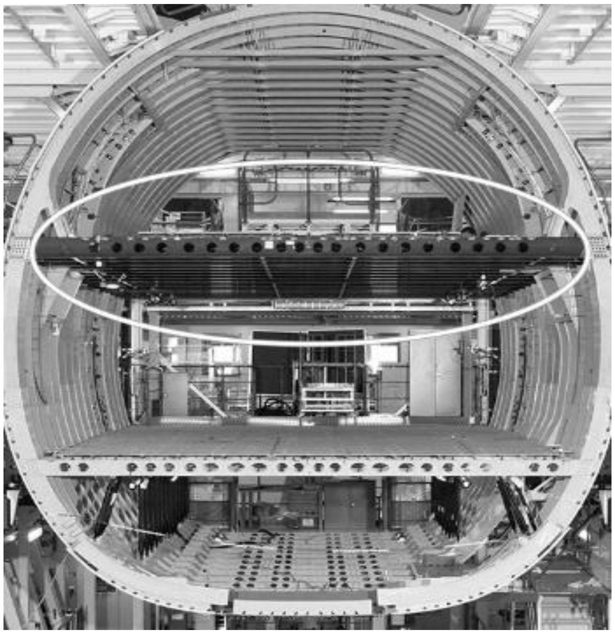


Fig. 17. Pultruded CFRP beams for the Airbus A380 Upper deck floors

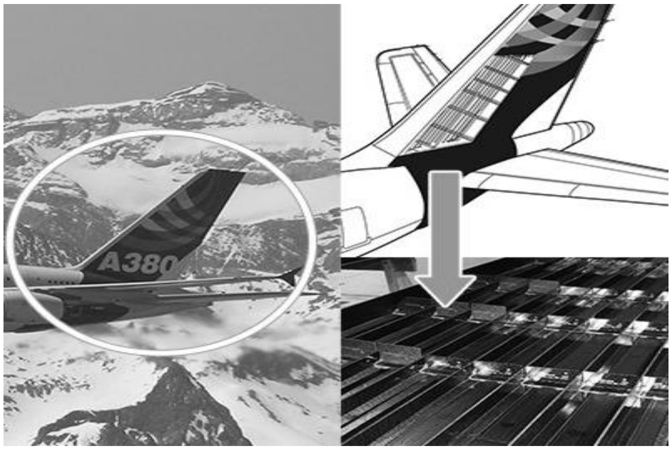


Fig. 18. Vertical Stabilizers of the A380 made from pultruded CFRP beams

7.4. Resin Transfer Molding or RTM Method

The RTM Method produces large and complex objects like aircraft parts, and automotive components. A set of molds are loaded with reinforcements and then later clamped together. The resin is then pumped or infused into reinforcement material. Curing is done after the mold is filled with resin. After curing, the mold halves are separated, and the part removed for final trimming and finishing.

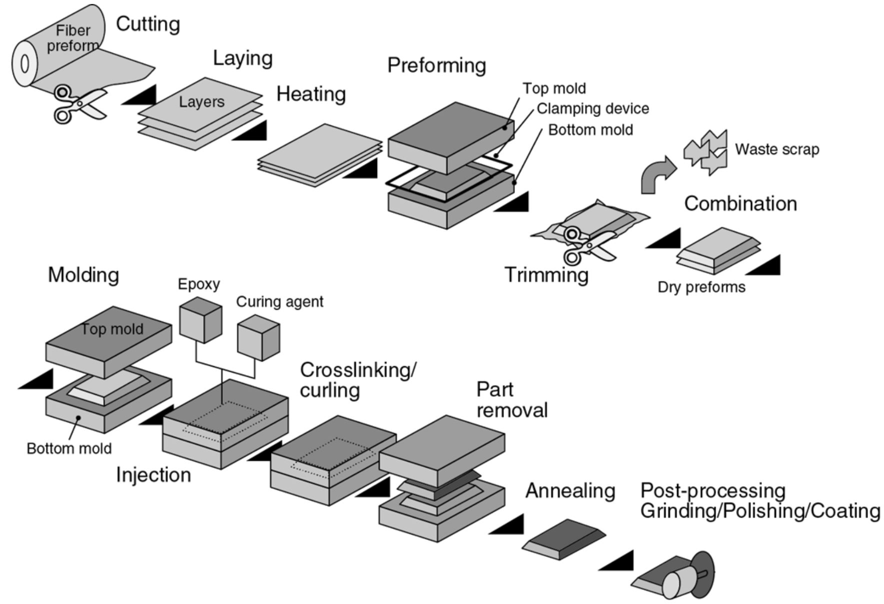


Fig. 19. The steps in RTM method

8.0. Conclusion

Composites are very vital in the construction of aerospace structures. Their specific characteristics make them very special. In years to come, the expansion of composite use in the aerospace industry will be visible in aircrafts made completely from composites. The manufacturing methods are also getting advanced and this will ensure better composite products be it easy -to- design laminates or complex structures.

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