Advanced composite materials of the future in aerospace industry

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Abstract: *Since Orville and Wilbur Wright first decided to power their Flyer with a purpose built, cast aluminium engine to meet the specific requirements for power to weight ratio, new materials have been necessary to improve and advance aviation. This improvement in material properties has helped us to travel quickly and inexpensively around the world, by improving the performance and operations of modern aircraft. In the first part of this study the author introduces the composites materials with their advantages and disadvantages. Airbus and its innovation in composite materials are introduced in the second part of the thesis. Composite technology continues to advance, and the advent of new types such as nanotube forms is certain to accelerate and extend composite usage. This issue is introduced in the last part of this thesis. Anyway, a continuing trend in material development is the improvement in processing and production of incumbent materials to either improve physical properties or to allow their application in new areas and roles for further usage in the future.*

Key Words: *composites, nanotube technology, carbon fibres, matrix, fibre reinforcement*

1. INTRODUCTION

There is a revolution underway in commercial aircraft manufacturing today and it can be summed up in one word: *composites*. There are many good reasons for aircraft manufacturers to use composites and for airlines to want composites to be used in their fleets. Many composite materials achieve relatively greater strength characteristics compared with traditional metallic materials, reducing aircraft weight and thus reducing fuel cost per passenger carried. Composites are more resistant than metal to fatigue from repeated take off/landing cycles, resulting in fewer costly inspections over the aircraft's lifespan and more time spent in the air making money. [1]

2. THE DEFINITION OF COMPOSITE MATERIALS

Composite material is a material that consists of strong carry-load materials which are embedded in a somewhat weaker material. The stronger material is commonly referred to as reinforcement and the weaker material is commonly referred to as the matrix. The reinforcement provides the strength and rigidity that is needed and which helps to support the structural load.

The matrix or the binder helps to maintain the position and orientation of the reinforcement and is somewhat more brittle. (See Fig.1) [2]

ROLES OF THE MATRIX AND REINFORCEMENT IN COMPOSITES:

The matrix is the continuous phase of the composite. Its principal role is to give the shape to the structure.

Therefore, matrix materials that can be easily shaped and then hold that shape are especially useful.

The matrix is the component of the composite that first encounters whatever forces might be imposed.

The principal role of the reinforcement is to provide strength, stiffness and other mechanical properties to the composite. [3]

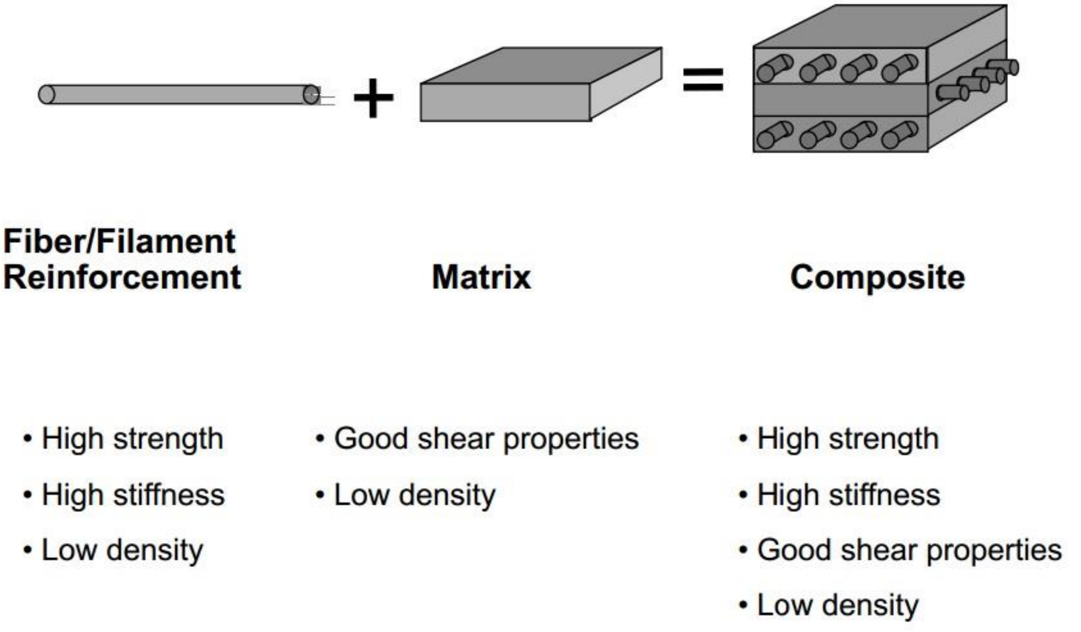

Fig. 1 Composition of Composites [3]

FIBRE COMPOSITE USE IN AIRCRAFT

Several types of composites are commonly used in the aerospace industry. For example, composites were first used for military aircraft during World War II.

Nowadays, they are used for private jets and modern commercial aircrafts in the aerospace industry.

It is important to note that the three most common existing types of composites are *reinforced with fiberglass, carbon fibre and aramid fibre.*

It is also interesting that each of these types has subtypes which provides for a wide variety of composites.

FIBERGLASS = is a fibre reinforced polymer made of a plastic matrix reinforced by fine fibres of glass. It is a lightweight, extremely strong and robust material. Although strength properties are somewhat lower than carbon fibre and it is less stiff, the material is typically far less brittle, and the raw materials are much less expensive.

CARBON-FIBER-REINFORCED POLYMER = is an extremely strong and light fiber-reinforced polymer which contains carbon fibers.

The composite may contain other fibers, such as aramid, e.g. Kevlar, Twaron, aluminium or glass fibres, as well as carbon fibres.

ARAMID FIBER = is a class of heart-resistant and strong synthetic fibres. They are used in aerospace and military applications, for ballistic rated body armour fabric and ballistic composites, in bicycle tires, and as an asbestos substitute. [4]

Every year the aerospace industry uses a higher proportion of advanced composite materials in the construction of each new generation of aircraft.

Back in the 1950s, when the most common composited of fibreglass was first used in the Boeing 707 passenger jet, composites accounted for 2% of the structure. By contrast, composites on the 787 account for 50% of the aircraft's structural weight and composites make up about 25% of the total airframe of the Airbus A380.

2.1 The advantages / disadvantages of composites in aviation industry

Composite materials are used more and more for primary structures in commercial, industrial, aerospace, marine and recreational structures.

Advanced composites do not corrode like metals – the combination of corrosion and fatigue cracking is a significant problem for aluminium commercial fuselage structure.

Composites today have a wide array of benefits in the aerospace and defence industry. Resulting fuel efficiency gained by an aircraft is becoming increasingly important with today's soaring fuel prices.

Other positive attributes include excellent fatigue and corrosion resistance and good impact resistance.

Composite usage has increased across aerospace and defence verticals, and some segments are expected to grow significantly in the next 20 years.

Going forward, the total composite market is anticipated to quadruple at a compound annual growth rate of 7.3 %, reaching US $30 billion by 2026. [5]

There are some advantages of composite materials:

1. Weight reduction – savings in the range 20% - 50% are often quoted
2. Mechanical properties can be tailored by 'lay-up' design, with tapering thicknesses of reinforcing cloth and cloth orientation.
3. High impact resistance – Kevlar (aramid) armor shields planes, too – for example, reducing accidental damage to the engine pylons which carry engine controls and fuel lines.
4. High damage tolerance improves accident survivability.
5. 'Galvanic' - electrical – corrosion problems which would occur when two dissimilar metals are in contact (particularly in humid marine environments) are avoided. Here non-conductive fibreglass plays a roll.

There are also some disadvantages:

1. Some higher recurring costs,
2. Higher nonrecurring costs,
3. Higher material costs,
4. Non-visible impact damage,
5. Repairs are different than those to metal structure,
6. Isolation needed to prevent adjacent aluminium part galvanic corrosion.

How we mentioned before, composite materials maximise weight reduction – as they typically are 20% lighter than aluminium and are known to be more reliable than other traditional metallic materials, leading to reduced aircraft maintenance costs, and a lower number of inspections during service. [2]

A Federal Aviation Administration Advanced Materials Research Program report found that for every pound of weight saved on a commercial aircraft, there is a US $100-300 cost saving over the service life of that aircraft. [6]

The Boeing 787 Dreamliner, with its widespread composite use in primary structures, will result in an aircraft that is 10,000 lb lighter and burns 20 % less fuel than a comparably-sized all aluminium aircraft. [7]

This shows that fibre composite use in aircraft results in significant weight savings, increased payload capacity and reduced fuel burn, allowing airlines using these aircraft to remain profitable in the face of rising fuel costs.

2.2 The usage of composite materials in aerospace industry

Composite materials can provide a much better strength-to-weight ratio than metals: sometimes by as much as 20% better.

The lower weight results in lower fuel consumption and emissions and, because plastic structures need fewer riveted joints, enhanced aerodynamic efficiencies and lower manufacturing costs. The aviation industry was, naturally, attracted by such benefits when composites first made an appearance, but it was the manufacturers of military aircraft who initially seized the opportunity to exploit their use to improve the speed and manoeuvrability of their products. [8]

Weight is everything when it comes to heavier-than-air machines, and designers have striven continuously to improve lift to weight ratios since man first took to the air.

Composites materials played a major part in weight reduction, and today there are 3 main types in use: carbon fibre, glass and aramid – reinforced epoxy.

There are others, such as boron-reinforced (itself a composite formed on a tungsten core). Composites are versatile, used for both structural applications and components, in all aircraft and spacecraft, from hot air gondolas and gliders, to passenger airliners or fighter planes.

The types have different mechanical properties and are used in different areas of aircraft construction.

Carbon fibre for example, has unique fatigue behaviour and is brittle, as Rolls Royce discovered in the 1960’s when the innovative RB211 jet engine with carbon fibre compressor blades failed catastrophically due to bird strikes.

In an experimental program, Boeing successfully used 1500 composite parts to replace metal components in a helicopter.

The use of composite-based components in place of metal as part of maintenance cycles is growing rapidly in commercial and leisure aviation. Overall, carbon fibre is the most widely used composite fibre in aerospace applications. [9]

THE AUTHOR'S SUMMARY

In my opinion, the demand for lighter and more efficient aircraft will ensure that there are considerable opportunities in aerospace for composite parts manufacturers over the next 15 years. We have to realise that the usage of composite materials in the aerospace industry is still going through a learning curve and further improvements will need to be made in the production process in particular for the market to reach its full potential.

For example, in the developed markets the global glass fibre reinforced plastic demand tends to focus on high-value applications, which are forecasted to be the driving force of composite market growth. This is really important matter of fact, indeed.

Customer demand requires glass fibre producers to develop better technologies to improve their process efficiency with lower costs.

Therefore, this innovation driven by consumers demand will create new and exciting opportunities for the composite market and this is the major goal.

3. COMPOSITES – A SIGNIFICANT MILESTONE FOR AIRCRAFT PRODUCTION

Advanced composites play a key role in aerospace innovation. Airbus has pioneered the use of composites and other advanced materials in aircraft design and manufacturing, resulting in an industry-leading product line of economical and environmentally-friendly jetliners – from the single-aisle A320 Family to the 21^{st} century A380 flagship.

The latest development in the field of aerospace materials arises from the use of application-specific materials.

The A380, which at 61% has the lowest percentage of aluminium by weight of all flying Airbus models, has 20 different alloys and tempers compared to the 6 utilised on the A320/330 aircraft.

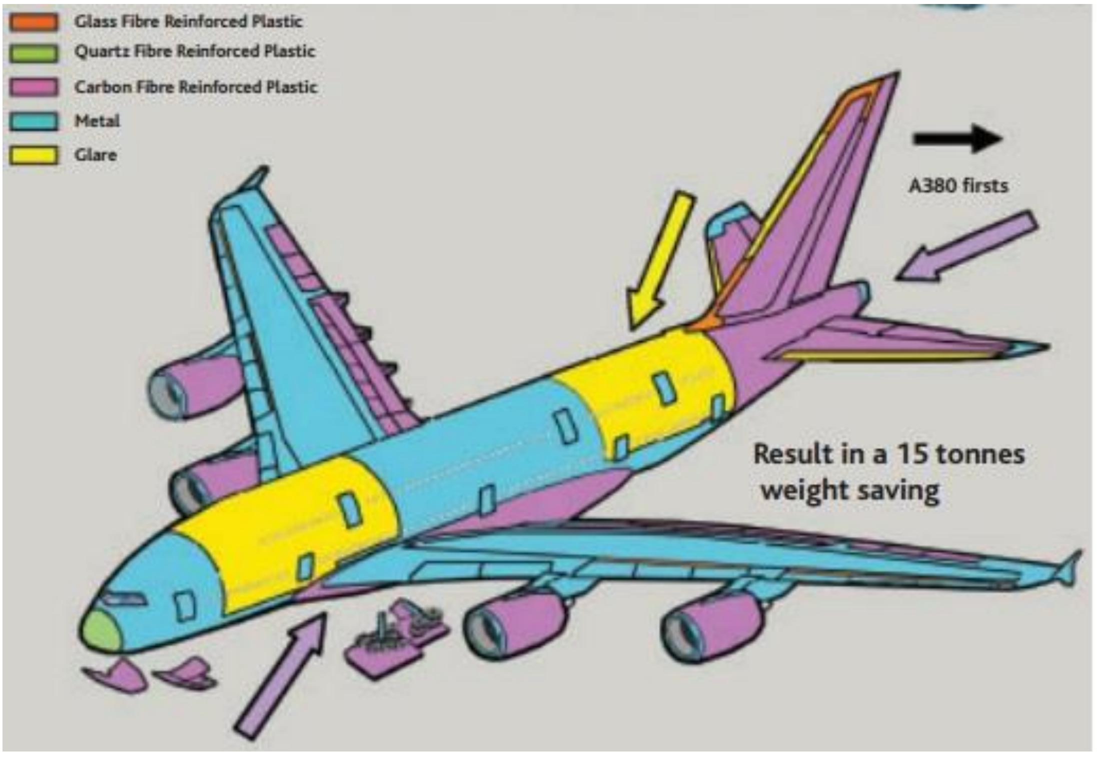

Fig. 2 Airbus A380 material composition [21]

3.1 Airbus and its innovation standard for composite environment

Airbus was the first manufacturer to make extensive use of composites and other advanced materials for producing large commercial aircraft, beginning with the A310 jetliner – based fin box.

Airbus pioneered the larger-scale use of composites for aviation over the course of some three decades.

For contrast, less than 5% of the cornerstone A300A310's total structural weight was made up of composite material during their pioneering production runs; while the percentage has significantly increased for Airbus' 21st century flagship A380 (almost 25%) and next generation A350XWB (more than 50%).

3.1.1 Composite structure of the Airbus A350XWB

The A350XWB consists of 53% composites, 19% AL/AL-Li, 14% Titanium and 6% steel. Composite skin panels are placed over composite frames and the cross section remains ovoid.

Aluminium strips in the frames ensure best results in dissipating lightening strikes. The rear fuselage section is a carbon fibre structure, as the horizontal stabilizer and fin / rudder assembly. (See Fig.3) [10]

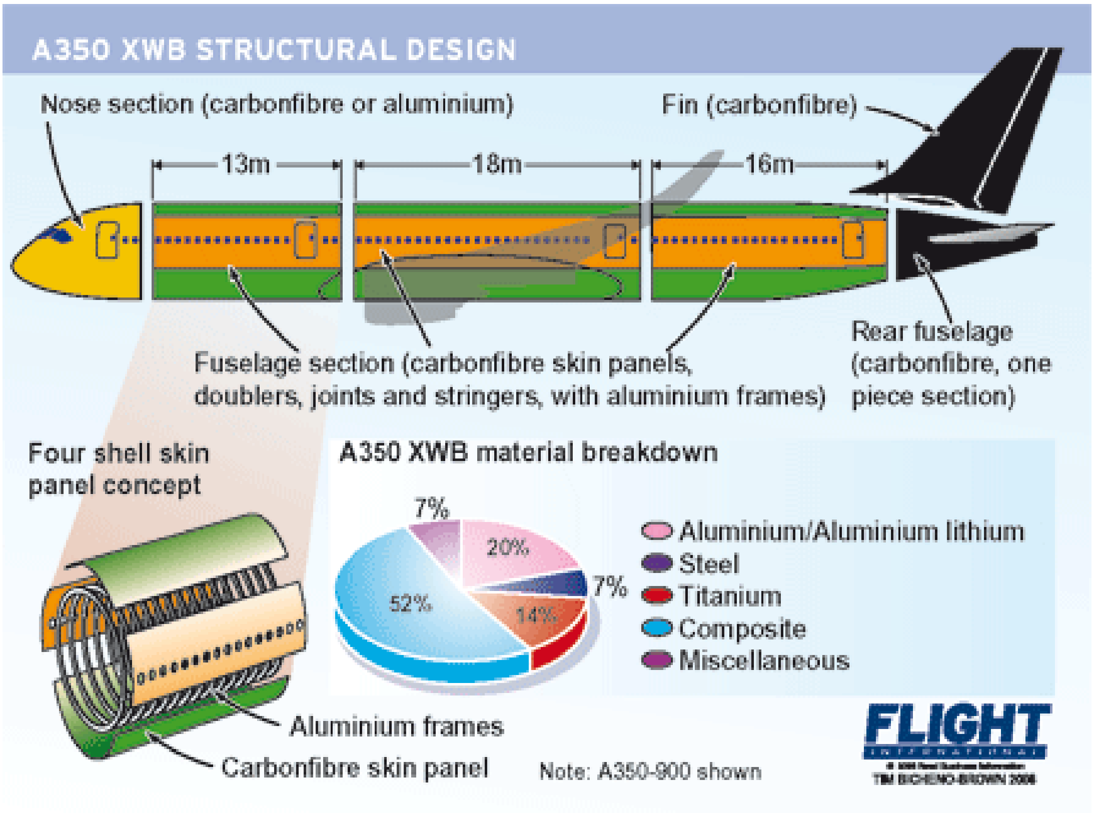

Fig. 3 Composite structure of A350XWB [22]

Its fuselage panels, frames, window frames, clips and door are made from carbon fibre reinforced plastic (CFRP), with a hybrid door frame structure consisting of this material and titanium being used for the first time.

By applying composites on the A350XWB, Airbus has increased the service intervals for the aircraft from six years to 12, which significantly reduces maintenance costs for customers.

The high percentage of composites also reduces the need for fatigue – related inspections required on more traditional aluminium jetliners, and lessens the requirement for corrosion-related maintenance checks. [9]

3.1.2 Composite structure of the Airbus A400M

In order to reduce weight, 30% of the A400M's structure is made of composites. These parts include most of the wing for the first time in history.

Also, nearly the entire tail (the horizontal and vertical stabilizers and the control surfaces), the rear cargo door, the sponsons (undercarriage bays) and the propeller blades (with Kevlar shell) are made of composite.

The wing's 19m / 62ft skin panels are the largest ever produced. The extensive use of composite material enables the A400M to be much lighter, enabling to enhance its performance both in terms of range and payload. [11]

3.1.3 Composite structure of the Airbus A380

Part of the goal in each aircraft company is to select the most appropriate material for the specific application, which would lead to the lightest possible structure. For this purpose, composite materials are good competitors, and their use is foreseen on many areas of the airframe.

The A380 is the first aircraft ever that boasts a CFRP (Carbon Fibre Reinforced Plastic) composite central wing box, representing a weight saving of up to one and a half tonnes compared to the most advanced aluminium alloys.

The upper deck floor beams and the rear pressure bulkhead are made of CFRP. For this last component, different technologies were tested such as Resin Film Infusion and Automated Fibre Placement. [11]

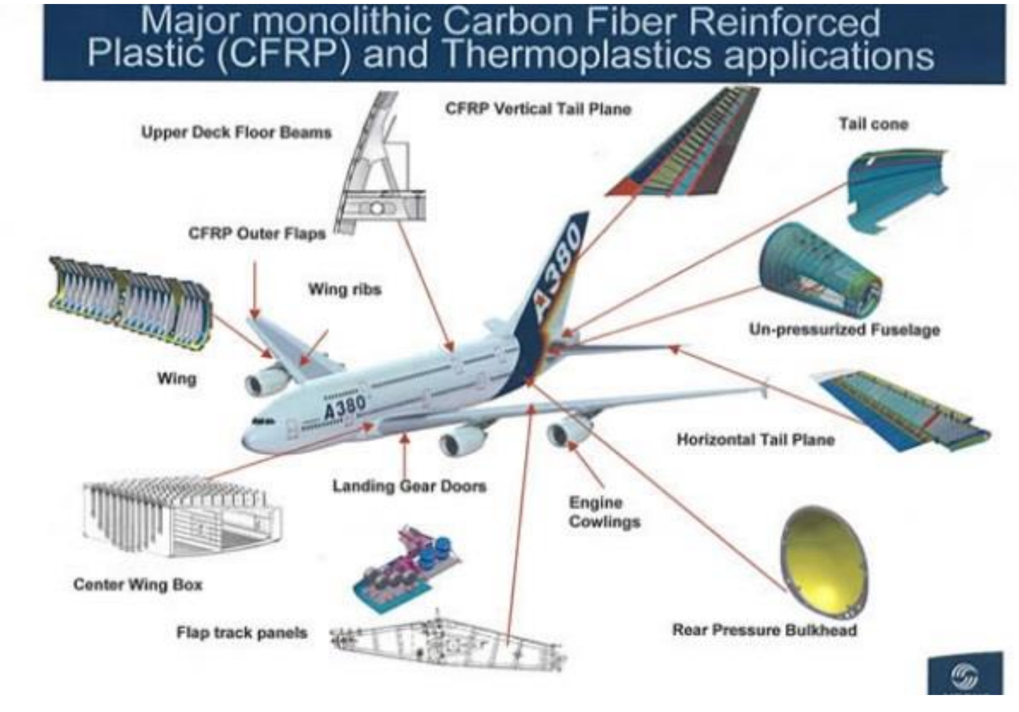

Fig. 5 Major monolithic CFRP and Thermoplastics applications [11]

THE AUTHOR'S SUMMARY

In an industry where quality, discretion and professionalism are paramount, we can see many leaders who are trying to lead the way it comes to design and manufacture of components for aerospace. So the purpose of composites in commercial air-planes is clear. But we have to take a look at different part of aviation. For example, general aviation and its business jets may use composite materials for their wings, but the fuselages will continue to be structured from aluminium alloys. Why? The answer is that we have to realise one thing, design engineers looking to save weight must consider 3 basic questions when choosing between composites and metal: How much weight are we saving, if any? What are the maintenance costs? And at least what are the production costs? Another question may be the same, regardless of the aerospace company you work for. But the answer can be different, if you work for Airbus or Gulfstream.

4. THE FUTURE OF COMPOSITES IN AEROSPACE INDUSTRY

With the 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.

4.1 The development of new composite materials

New materials can be defined as materials which have yet to be applied in an ‘as-designed’ application in aviation. Some of these materials, particularly metal matrix composites (MMC) and ceramic matrix composites (CMC) have seen some in-flight testing and are approaching military use but have yet to gain wide ranging acceptance by OEMs for various reasons.

4.1.1 Ceramic matrix composites (CMCs)

It is a material with the excellent thermal properties and with improved mechanical properties and with improved mechanical properties, overcoming the limitations of monolithic ceramic (i.e. toughness) and displaying other benefits. The possible applications of CMCs in aviation are generally in the hot section of the aero engines and include turbine disks, combustor linear, and turbine aerofoils. [12]

4.1.2. Metal matrix composites (MMCs)

These consist of an aluminium or titanium matrix with oxide, nitride or carbide reinforcement and have many advantages over monolithic materials. But they are not as tough, are more expensive and are difficult to machine. Possible applications include highly loaded surfaces such as helicopter rotor blades, turbine fan blades and floor supports. [12]

4.1.3. Carbon Nanotube technology

Carbon nanotubes have been being looked forward to as the next generation of new and advanced materials. System designers are now seeing the possibilities of using these in new applications for electronics and shielding of large scale aircraft.

Carbon nanotube technology has many applications for aerospace and defence electronics. It is EMI shielding, for example, carbon based composite aircraft often get residual current from lightning strikes. They use metal to protect the aircraft, but residual current is still present. This light weight material is being used for EMI shielding and shielding internally. It enables better shielding for basically the weight of a coat of paint, and allows you to shield the internals of a carbon fiber based airplane.

Carbon nanotubes have at least the tensile strength of carbon fiber, but they are quite flexible. They don’t have the same brittleness, so the strain to failure is different. They are able to be in a fabric like format where they can be put into the composite themselves, or be the composites themselves.

One can imagine that the surface of a wing would be both structural, it would de-ice itself, it could be the antenna, it could report back to the aircraft and say ‘we are or we are not integral’, you have enormous numbers of multifunctional applications that carbon nanotube technology can bring to aircraft and spacecraft. [12]

4.1.4 Shape memory metals (SSMs)

When SSMs are heated they revert to predeformation shape. They usually consist of copper/nickel based alloys, though other materials can be used. The simplicity of SSM actuators is that they can be used for hybrid applications such as variable jet intake and morphing variable geometry chevrons where traditional systems are too large and complex when compared with the savings possible. [12]

4.1.5 Core materials

Aerospace sandwich structure consists of two skin face sheets attached to a core using adhesive. There are many materials utilized in the development of a core. The most common type of core is a honeycomb.

Depending on the design parameters of the part, the aerospace industry may utilize either metallic or non-metallic honeycomb material. A honeycomb core is made from materials such as aluminium, fibreglass or Nomex.

The honeycomb sandwich construction can comprise an unlimited variety of materials and panel configurations.

The composite structure provides great versatility as a wide range of core and facing material combinations can be selected. [13] [14]

Honeycomb-cored sandwich panels increase part stiffness at a lower weight than monolithic composite materials.

By imitating the natural geometric structure of a beehive, the honeycomb core imparts strength and light weight to sandwich panels, while supporting the prepreg skins.

The honeycomb sandwich structure composite has high compressive strength in the direction of the cell walls and high shear strength in the plane perpendicular to the cell walls. Commonly, the bond between the honeycomb core and the prepreg skins is created by a film adhesive layer.

A surfacing film is often co-cured with the composite sandwich panel to improve the appearance of the part and to provide a smooth, uniform, and nonporous surface. [15]

4.2 The companies in aerospace composites excellence

GE Aviation, a world-leading producer of jet engines, already employs more than 450 people at a factory in northwest Mississippi.

This factory is involved in the assembly of large front fans for jet engines as well as the production of composite components. The specific type of composite materials is known as Polymer Matrix Composites.

They are made of carbon fiber fabric and polymer resin and fabricated by using advanced technology in manufacturing processes and equipment. [16]

4.2.1 Hexcel – a leading advanced composites company

A world leader in carbon fiber and composite materials for commercial and defense aircraft, helicopters, engines, HEXCEL is also a specialist in lightweight composite including engineered core parts, HexMC components and complete structures.

Hexcel's composite materials bring great benefits to aircraft design. The improvement in fatigue performance with carbon fiber reinforced prepregs compared to Aluminium is also a major benefit.

More than 50 % of the Boeing 787 airframe and the Airbus a350XWB is carbon fibre composite. Hexcel is a major supplier of materials to both programs and was awarded the contract to supply all the primary structure prepreg (with Hexcel carbon fiber) to the A350 XWB program.

Fig. 6 HexTow Carbon Fiber for Aerospace [17]

Hexcel has 40 years' experience in carbon fiber manufacture, with a vast Aerospace database and manufacturing facilities in the USA and Europe.

It is an Intermediate Modulus fiber technology leader with an in-house Polyacrylonitrile (PAN) domestic supply and dedicated R&T facilities for both precursor and carbon fiber development. HexTow carbon fiber supports the World's most advanced applications including: A350 XWB, JSF, F18 E/F, A380, Eurofighter Typhoon, A400M, Boeing 787, and GENX Engines. [17]

4.2.2 Blackhawk Composites – gain a competitive edge

Advanced composites play a key role in aviation industry. Aircraft operators, both commercial and military, have shown that there is a demand for product upgrades, and Aftermarket providers have responded with solutions – often incorporating composites – that enhance the performance and efficiency of legacy aircraft.

From cowlings and fairings to storage lockers, Blackhawk Composites has complete capabilities to design, prototype and build composite components, using a wide variety of reinforcements and resin matrices, required for advanced aerospace applications, including custom solutions to meet specific performance objectives.

Blackhawk Composites is one of just a few companies approved to utilize TORAY carbon epoxy composite material, the same material used on commercial jetliners and favored by the FAA.

Fig. 7 Aviation affiliate - Blackhawk Modifications [18]

Blackhawk Modifications, a leading aircraft performance company, recently certified an engine upgrade solution for the Cessna Caravan 208B. Working with Blackhawk Composites, a design team engineered and manufactured a new composite cowling to accommodate the upgraded aircraft's larger, more powerful engine and dual port exhaust.

Also, the Carbon/Epoxy composite materials pass 16 different tests, using 5 samples each, for a total of 80 test conditions. [18], [19], [20]

THE AUTHOR'S SUMMARY

What is the major goal of composite materials and their usage in aviation? This question is clear nowadays.

Composites are one of the most important parts of aircraft's production. The recent studies show that, for example, glass fibre composites are the most popular due to their cheap price and ease of manufacturing, and will remain as the largest submarket – both in volume and value – of composites throughout the forecast period.

My another point of view is focusing on the carbon fibre composites that are expensive, but favoured in demanding applications, such as in the civil and military aviation, either. According to further researches we can see that other fiber composites and hybrids are forecasted to grow strongly, as sophisticated and purpose-built composites will become necessary for new applications.

5. RESULTANT CONCLUSIONS

Composite materials are becoming more important in the construction of aerospace structures. New generation large aircraft are designed with all composite fuselage and wing structures and the repair of these advanced composite materials requires an in-depth knowledge of composite structures, materials and tooling.

The carbon nanotube technology itself is the greatest challenge for being able to drive scale to volume and decrease cost.

For example it is great to have a cable that's 69% lighter weight, but you have to be able to produce this in a format and in a cost that can be broadly used by aircraft engineers. So the future is driving up the output, decreasing cost and eventually getting broadly used across the entire industry.

The future of the composite industry looks set for continued expansion, with mergers and acquisitions likely, long term growth guaranteed, and exciting new innovative products and applications always on the horizon.

Partners in composite excellence are the source for quality composites solutions that meet exacting aerospace requirements.

We have to realize that all companies are an intelligent partner involved in and invested in better composite aviation world.

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