Airframes – Instructor Training Manual

Chapter 2 – MATERIALS

Learning Objectives

1. The purpose of this chapter is to make you aware of the many different materials employed in an aircraft's structure, it's properties and application.

2. So, by the end of this chapter you will be able to identify the main materials used in aircraft construction, where they are used and what properties are beneficial in supporting the design.

Introduction

3. In previous chapters we have stressed that the materials used in structural areas of airframe construction must have a high ratio of strength to weight. The following groups of materials come into this category, and are used for the main structural parts:

- Aluminium and magnesium alloys (*Light* alloys)
- Steels and steel alloys
- Titanium and its alloys
- Plastics and composites
- Carbon fibre re-forced plastic (CFRP)
- Glass re-inforced aluminium laminate (Glare)

4. It is difficult to say exactly how different materials compare with each other, because there are so many different factors to consider. For example, some resist tension (stretching) better than others; some resist compression better, and so on. Even different types of aluminium alloys are preferred by different types of loads. But we can get an idea of how different materials compare by considering their
strength-to-weight ratio (SWR).

5. There are other things to consider apart from the SWR:

A material must also be consistent and predictable in its properties, so that we know what behaviour to expect from it.

It should be homogeneous, i.e having the same properties throughout, although the way a particular material is processed may upset this. If it does, it must do so in a predictable way, and leave the material is a useful state.

It must not suffer badly from corrosion or other deterioration caused by exposure to the weather, sea water or any chemicals that it comes into contact with. In particular, subjecting some materials to high loads and corrosive fluids can cause *stress-corrosion cracking.*

It should be non-inflammable (magnesium alloy can burn fiercely when exposed to high temperatures such as a fuel fire so it's application is considered carefully).

It should be readily available and at reasonable cost, and should be easy to work with using standard processes.

It should not suffer badly from fatigue, or must be used in parts which are not subject to fatigue conditions (see later section on this).

ALUMINIUM AND MAGNESIUM ALLOYS

6. Pure aluminium and pure magnesium are completely unsuitable as structural materials for an airframe, but when alloyed (chemically mixed) with each other or with other metals, they form the most widely-used group of airframe materials. These alloying metals include zinc, copper, manganese, silicon and lithium. There are many different variations, running into dozens, each having different properties and so suited to different uses. Magnesium alloys are very prone to attack by sea water, and their use in carrier-based aircraft is avoided.

Aluminium lithium alloys are superior to Al-zinc and Al-copper alloys in many respects, but cost around three times as much, so their use is limited. An interesting property which aluminium shares with titanium is that it can be superplastically formed (SPF). When the material is heated to a certain temperature, but below its melting point, it becomes extremely pliable, like rubber. It can then be inflated to fill a mould and take its shape exactly. This can be used to make extremely complicated shapes cheaply and with minimum weight, although the high initial cost of tooling means it is limited to fairly large production runs.

7. Advantages:

- High strength/weight ratios.
- A wide range of different alloys, to suit a range of different uses.
- Light, so greater bulk for same weight means they can be used in greater thicknesses than heavier materials, and thus are less prone to local buckling; this applies to magnesium alloys even more than aluminium alloys.
- Available in many standard forms - sheet, plate, tube, bar, extrusions.
- Easy to work after simple heat treatment.
- Can be super-plastically formed.
- Reasonable electrical and magnetic screening properties.

Disadvantages:

- Subject to corrosion, so need protective finishes.
- Subject to fatigue

STEEL AND ITS ALLOYS

8. Steel is made by alloying pure iron with a wide range of other elements. This gives the possibility of producing a wide range of material properties. Steels will always contain carbon, and may contain one or more of the following; chromium, nickel and titanium. Steels can be produced with a wide range of properties, ranging from extremely hard to very ductile (able to be bent and stretched). However, they all share one property, and that is that steel is heavy. Steel finds most usage where its strength can be used to best advantage, for instance where space is limited, or where its hardness and toughness are needed. The most common use is in bolts and other fasteners. It has one more advantage - it performs much better at higher temperature than most other materials except titanium, and was used for Concorde wing skins, and inside engines.

9. Advantages:

- Cheap and readily available.
- Consistent strength
- Wide range of properties available by suitable choice of alloy and heat treatment.
- High strength useful where space is limited.
- Some stainless steels are highly resistant to corrosion.
- High-tensile steels have high SWR.
- Hard surface is resistant to wear.
- More suitable for use at higher temperatures than light alloys, but not as good as titanium alloys.
- Easily joined.
- Very good electrical and magnetic screening.

Disadvantages:

- Poor SWR except high tensile alloys.
- Heavy, so care must be taken not to use very thin sections, or buckling will result.

TITANIUM AND ITS ALLOYS

10. Titanium and its alloys are expensive but its main advantage is its high SWR. Its properties are very similar to steel but it is lighter and it is very good at maintaining its strength even at high temperatures. It is widely used in jet pipes, compressor blades and other components that are subject to high temperatures. Like aluminium alloys, titanium can be super-plastically formed, allowing very strong and light items, such as pressure vessels, to be made. Titanium has

another related property, that of diffusion bonding. At a precise temperature, two pieces of titanium pressed together will fuse and become a single piece. When combined with SPF, this allows even greater flexibility of design.

Recently with the increased use of carbon fibre reinforced plastic (CFRP), titanium components have been selected by designers for two important reasons. Firstly, its co-efficient of thermal expansion is very low, similar to that of CFRP, which allows these two materials to be bolted together and minimize the effects of thermal strain (this is strain induced in the aircraft airframe when the temperature changes). Secondly, the potential difference between the two materials is very low which minimizes the effect of galvanic corrosion. This means that it is safe to put these two materials in contact with each other without the risk of causing one of the materials to preferentially corrode. (Note: Aluminium is different from titanium in this respect and should always be insulated from CFRP otherwise it will corrode.)

11. Advantages:

- High strength/weight ratio.
- Maintains its strength at high temperatures.
- Higher melting point and lower thermal expansion than other materials.
- Can be super-plastically formed and diffusion bonded.
- Resistant to fire.

Disadvantages:

- Expensive.
- Can be difficult to work, especially machining.
- Poor electrical and magnetic screening.
- A very hard scale forms on the surface at high temperatures.

COMPOSITES MATERIALS

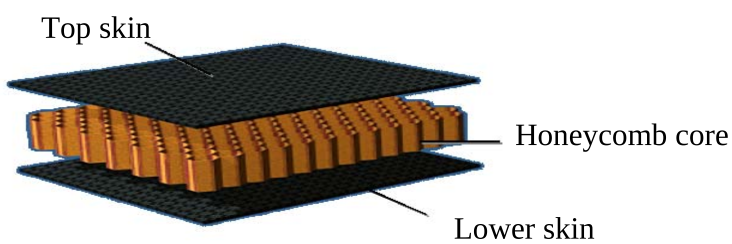
12. Composite materials are now being used much more extensively for aircraft structures. This is because the weight saved in the construction of a lighter airframe can be used to increase the aircraft performance, be it acceleration or range important factors for a fighter or transport plane respectively.

A composite is constructed from two or more different materials combined together to give a material with increased physical properties. This usually means combining fibres of materials such as glass, carbon, boron or Kevlar (a trade name for aramid fibre) with a *thermosetting* resin such as epoxy. The most common composite used for aircraft construction is carbon fibre reinforced plastic often abbreviated to CFRP and was certified for use by Boeing in 1974 for use on the 737 and 727. The material properties of a finished composite component are not always the same in every direction. The component is said to be anisotropic and it is down to the design of the component as to how strong it is in a certain direction, this is an important difference to other aircraft components such as those made from metal alloys.

It is important to remember that not all composites are CFRP, sandwich panels may be constructed from CFRP with a paper or aluminium honeycombe core. Also aluminium and glass fibres may be combined (see later section on Glare) and in the future composites with a ceramic matrix and silicon fibres could be used for high temperature applications.

Composites are commonly used to construct panels, which consist of a sandwich of, for example, carbon-fibre/Kevlar-honeycomb/carbon-fibre (see Figure 4-1). Composite sandwhich panels are used on all Airbus aircraft because they have a very high strength to weight ratio and are far better at resisting bucking than a sheet of metal.

Fig 4 : Sandwich panel construction



Up until recently the use of composite materials has been limited to the construction of components within the interior of the fuselage and aircraft secondary structures, such as panels on the wings and engines. In modern aircraft such as the A400M military transport and the A350 airliner a large proportion of the aircraft can now be made from composite material and this is possible due to the fact that composites are now applied to the construction of primary structure. For example both of these aircraft utilize composites for the front and rear wing spars and top and bottom wing skins, the A400M is approximately 48% by weight composite. The airframe of the Eurofighter Typhoon is built using up to 50 % by weight composite material (not including engines, weapons ect.). Although comparable in dimensions to the Tornado, the empty weight of the Eurofighter is 70% that of the Tornado, this illustrates the weight savings the use of such materials can confer to an aircraft.

Lightning strike

13. A disadvantage of carbon composite material is that it is a poor electrical conductor so a bronze or copper mesh has to be added to certain area of the component during manufacture. This is done so that if the aircraft is stuck by lightening the current can be safely carried away from the location of the strike and dissipated across the rest of the aircraft structure.

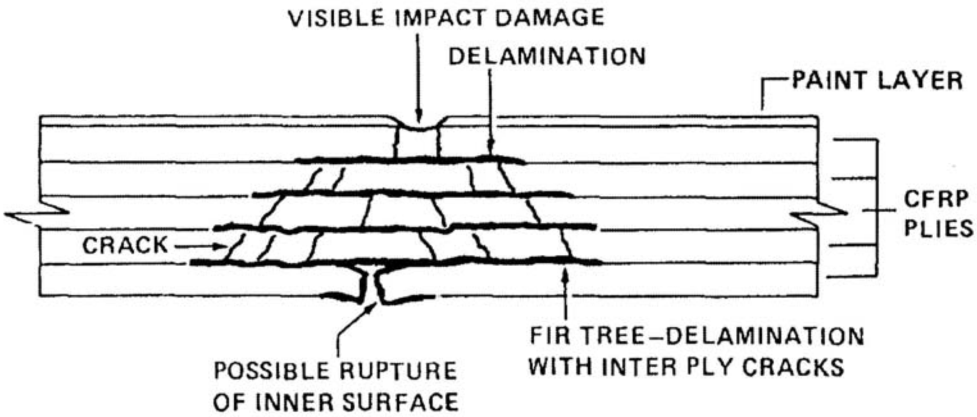
Electromagnetic shielding

14. Another disadvantage of carbon composite is that is very poor at providing an electrical and magnetic shield for the electrical cables of the to the aircraft's systems. Extra shielding has to be added to the structure to protect the system cables and this adds weight, cost and complexity to the component. For instance an aircraft is exposed to strong electromagnetic fields, on the deck of a ship, or in the event of a nuclear explosion, the electmagnetic pulse (EMP) can induce strong electrical currents in the aircraft's electrical system, which may cause it to fail

Composite Damage

15. In general composites are much better in fatigue than metallic structures but composites are not as damage tolerant. For the safety reasons it is import to be aware of composite damage.

16. Initially an impact can cause a small dent on the surface but the underlying damage could be much more extensive beneath the surface, matrix cracking, fibre crushing and delamination may have taken place in an area much larger than the mark left by the original impact.



Great care must always be taken to prevent dropping tools or striking a composite with metallic objects. It is important to prevent knocks and collision damage, especially to the edge of a composite because this area is very vulnerable.

Composite Repair

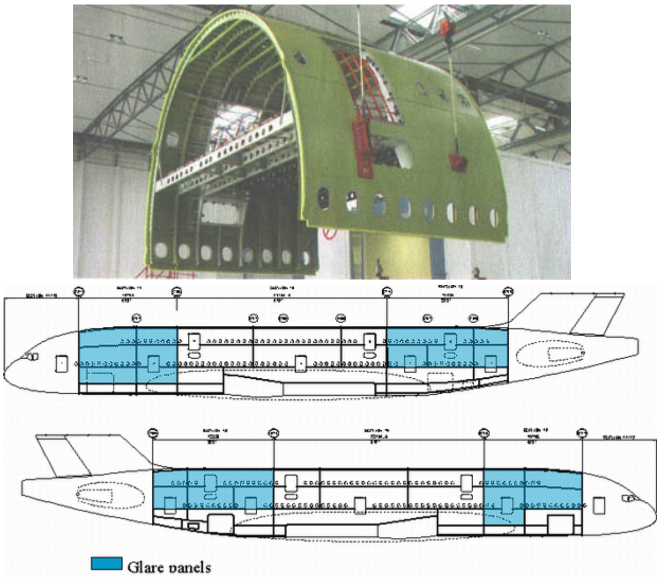
17. The repair method selected will depend on the type of structure that is damaged and there are basically 3 types.

- A bolted repair will involve machining off the damaged material and bolting in place a repair plate, which is often metallic.
- A cold bonded repair is when the damaged area is repaired with a matt of composite fibres saturated with a cold-curing adhesive resin. This is usually used in areas that have low strength.
- A hot bonded repair uses a fibre matt pre-impregnated with resin and the repair is cured by applying a controlled heat blanket connected to a control box, which controls and records the cure temperature.

Glass re-inforced aluminium laminate (Glare)

18. A very commonly used aircraft material used for the construction of panels is a composite of glass re-inforced aluminium laminate, which has the trade name 'Glare'. It is constructed from alternate layers of aluminium sheets with re-inforcing sheets of unidirectional glass fibre. This material has a low susceptibility to corrosion as the glass layers act to retard moisture and also improve its resistance to fire. The material has a better impact resistance than CFRP, is less susceptible to cracking than aluminium alloy and is 10-30% lighter than aluminium but the disadvantage is that it is more expensive. Skin panels of Glare are used in the construction of the fuselage of the Airbus A380.

Figure: Construction of Airbus A380 fuselage sections using Glare panels



Advantages and disadvantages of composite material

19. Advantages:

- Very high strength/weight ratio.
- Good in fatigue.
- Available in a wide range of forms.
- Low resistance to radar and radio signals and is ideal for radomes and antenna
covers.

Disadvantages:

- Need special manufacturing and repair methods.
- Strength and stiffness is not the same in all directions.
- Poor electrical screening.
- Requires specialist NDT inspection techniques to find damage.
- Can absorb water (especially honeycomb panels).

Non Destructive Testing (NDT)

20. In service maintenance requires the aircraft to be inspected so that it can be checked that it is safe to fly. NDT can be used on composite and metallic components to check that there is no hidden damage inside the material, which is going to weaken the airframe and this can be done in a number of different ways;

- Visual
- Acoustic (commonly a tap test)
- X-ray
- Thermal
- Ultra-sonic

21. Ultrasonics are probably the most common form of NDT for composite materials and in its simplest form works in a similar way to a submarine's sonar pulse, using a 'sound' or vibration of several megahertz (million cycles per second, hearing limit is around 20 thousand cycles per second). The pulse echo method uses a pulse of vibrations passed from a probe in to the surface of the composite, the same probe then detects the strength and delay of the echo from the back wall or defect. This is easy to apply to a structure where the rear surface cannot be easily reached, the component is very large, or cannot be removed from the aircraft.

FATIGUE

22. Fatigue is a material's tendency to break under a high number of relatively low stresses, such as take-offs and landings or under vibration. Next to human factors, it is the chief cause of aircraft accidents. To guard against such failures, aircraft life is often quoted in flying hours. For example an RAF training aircraft has a life of 5,000 flying hours while in contrast an airliner such as the Airbus

A350 150,000 flight hours or 30,000 flight cycles (A service trainer is expected to suffer much more severe treatment than an airliner!). Fatigue meters are fitted to most RAF aircraft and record the number of times a particular load is reached when flying the aircraft. The manufacturer carries out a long series of fatigue tests on an airframe, to find out when problems are likely to happen. By comparing the information recorded by the fatigue meter with the manufacture's tests, remaining airframe life can be constantly monitored.