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Airframes

Revision 1.00

Chapter 2:

Materials

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Learning Objectives

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.

So, by the end of this presentation 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.

But first a recap of Chapter 1 with some questions.

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Chapter 1 Revision

A few questions about the previous chapter.

1. How many major components make up an airframe?
2. Name the **5** types of forces (or loads) that would be present in components of an aircraft wing?
3. What structural element is used to counter a tensile force (or load)?
4. What is a ***'Cantilever'*** and can you name any examples?

Materials

In the early days of aviation, airframes were built from wood, canvas and steel wire.

However, modern airframe designs use a variety of different materials in their construction and it now common to find the following materials within the main structure.

Carbon Fibre Reinforced Plastic (CFRP)

Aluminium and Magnesium Alloys

Plastics

Glass re-infored aluminium laminate (Glare)

Titanium and Titanium Alloys

Composites

Steel and Steel Alloys

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Material Design Factors

Due to the many different factors to consider, it is difficult to say how different materials can be compared.

- Some will be better at resisting **tension** (stretching) better than others
- Some will be better at resisting **compression** (squashing)
- Other materials will be better at coping with extremes of **temperature**
- And so on……..

Even different types of aluminium alloys are preferred for different types of loads.

Material Properties

It is important that the materials used in Airframes be consistent and predictable in their properties – so we know what behaviour to expect from them!

The material to be used should be ***homogeneous*** (i.e It has the same properties throughout).

- However, the way in which a particular material is processed may upset this
- If it does, it must do so in a predictable way and leave the material in a useful state

The material should be readily available and at reasonable cost with the ability to be worked using current processes.

Material Properties

They should be able to withstand corrosion or other deterioration due to environmental effects

- Weather, sea water or man made chemicals that it may come in contact with
- Subjecting some materials to high loads and corrosive fluids can lead to *Stress Corrosion Cracking*

The material should be incapable of supporting a fire

- Magnesium alloys can burn fiercely when exposed to high temperatures

However, they should NOT suffer badly from fatigue (damage caused by stress).

- Or if to be used, can only be used in parts that are not subject to fatigue conditions

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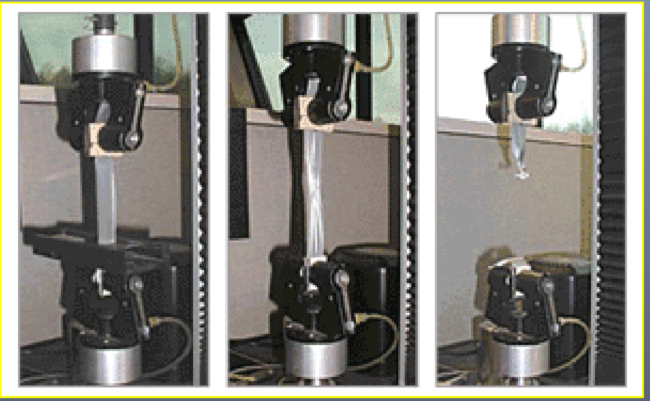
Strength to Weight Ratio

The best way to compare different materials is by considering their ***Strength to Weight Ratio.***

- i.e. How much weight can be hung from a sample of the material before it fails under the excessive loading.



However, there are other things that can be considered as well as the *Strength to Weight Ratio.*

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Aluminium and Magnesium Alloys

Pure aluminium and magnesium are completely unsuitable as airframe structural materials.

To be able to use them, they need to be alloyed (chemically mixed) with each other or with other metals, such as;

Zinc

Manganese

Copper

Silicon

Lithium

Once alloyed, they form the most common used of all airframe materials. Alloying allows for variations in properties, so that they can be tailored to different uses.

Aluminium and Magnesium Alloys

Aluminium Lithium alloys are superior to Al-Zinc and Al-Copper alloys in many respects.

- But they cost around three times as much, so their use is limited.

An interesting property of Aluminium is that, like Titanium, they can be *Super-plastically Formed (SPF).*

When the material is heated to a certain temperature just below it's melting point, it becomes extremely pliable – much like thermoplastics.

It can then be inflated to fill a mould and take the shape exactly.

Al & Mg Alloy Advantages

The advantages of using Aluminium and Magnesium Alloys are:

- They have a high *Strength to Weight Ratio* and Can be alloyed with a wide range of other materials to suit a number of applications.
- They are generally lightweight, so can be used in greater thickness than heavier materials and are therefore less prone to local buckling.
- The material is available in many standard forms – sheet, plate, tube, bar, extrusions and is easy to work after simple heat treatment
- They have reasonable electrical and magnetic screening properties

Al & Mg Alloy Disadvantages

But, Aluminium and Magnesium alloys do have some disadvantages, specifically;

- Both Aluminium and Magnesium Alloys are subject to corrosion and need to have protective finishes applied.

- Both Aluminium and Magnesium Alloys are subject to fatigue and therefore it’s use in highly loaded components must be carefully restricted.

Steel and Steel Alloys

Steel is itself an alloy of pure iron and is therefore a *Ferrous* material

Steels will always contain carbon and may contain one or more of the following materials;

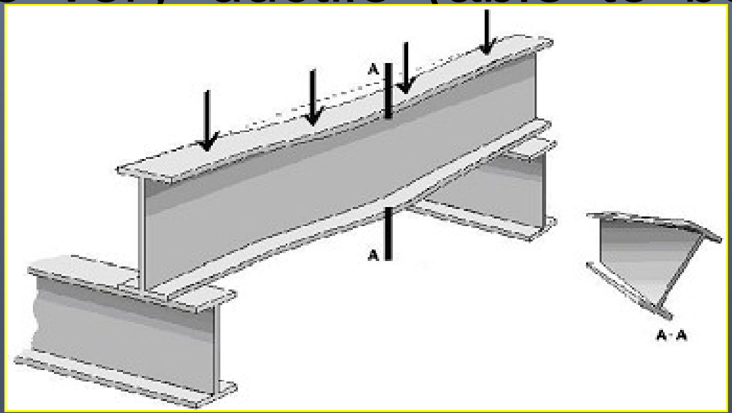
Nickel

Titanium

Chromium

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 are all HEAVY, so prone to local buckling



Steel and Steel Alloys

Steel finds most usage where it's strength can be used to best advantage

– i.e. Where space is limited or where it's hardness and durability are needed. Therefore, it is most commonly used in bolts and other fasteners.

It also performs better at higher temperatures than most other materials

– With the exception of Titanium!

Steel and It's Alloys - Advantages

The advantages of using Steel and Steel Alloys are:

- The material is cheap and readily available
- Consistent strength – useful where space is limited. High tensile steels have a High *Strength to Weight Ratio*
- They have a wide range of properties available by suitable choice of alloy and heat treatment. Some Stainless Steels are highly resistant to corrosion
- Hard surface that is resistant to wear
- More suitable for use at higher temperatures than light alloys, but not as good as Titanium Alloys
- Easily joined and have very good electrical and magnetic screening

Steel and It's Alloys - Disadvantages

Even with all those advantages, they do have some disadvantages;

- With the exception of High Tensile Alloys, the vast majority have a poor *Strength to Weight Ratio*.

- The material is heavy, so care must be taken no to use very thin sections, or buckling will result.

Titanium and It's Alloys

Titanium and it's alloys are expensive, but they have a high *Strength to Weight Ratio*

Titanium has properties close to steel, but are much lighter

- Can also maintain strength at high temperatures
- Hence the material is used extensively within Gas Turbines for components such as;

Jet Pipes

Casings

Ducts

Compressor Blades

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Titanium and It’s Alloys

Titanium can be *Super-plastically Formed*, which allows very strong and light items to be manufactured, such as pressure vessels

Titanium can also be *Diffussion Bonded*, where two pieces of titanium are pressed together (at a precise temperature) and will fuse to become a single piece

- This allows for greater flexibility of design when combined with *Super-plastic Formation*

Titanium and It’s Alloys

With the increase in the use of Carbon Fibre Re-inforced Plastic (CFRP), Titanium components have become more attractive to designers

- The *Co-efficient of Thermal Expansion* of Titanium is very low – similar to that of CFRP, so that the two materials can be bolted together
- This minimises thermal strain experienced when the airframe temperature changes
- Potential difference between the two materials is also very low, which minimises *Galvanic Corrosion*.
- Therefore it is safe to have these two materials together as the risk of causing one to preferentially corrode is small

Titanium and It's Alloys Advantages

The advantages of utilising Titanium and Titanium Alloys within airframes are;

- They have a much higher *Strength to Weight Ratio* than Steel
- Titanium and Titanium alloys maintain their strength at high temperatures
- They have a higher melting point and lower thermal expansion than other materials
- The material can be *Super-plastically Formed* and *Diffusion Bonded*
- Titanium is resistant to Fire, therefore it's use is more prevalent in high temperature areas.

Titanium and It's Alloys Disadvantages

Like all materials, there are disadvantages in using Titanium, specifically;

- Titanium is an expensive material
- It can be difficult to work – especially to machine
- It has poor electrical and magnetic screening
- A very hard scale can form on the surface of Titanium at high temperatures

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Plastics & Composites

A *Composite* is simply **two or more** different materials combined to provide a material with enhanced physical properties.

- Usually a combination of fibres such as glass, carbon, boron or Kevlar with a *Thermosetting* resin such as epoxy

- The most commonly used composite within airframes is Carbon Fibre Re-inforced Plastic (CFRP)

Until recent times, composite materials have been limited to the construction of components within the interior of the fuselage and secondary structures

- Areas such as panels on wings, tail and engine nacelles

Plastics & Composites

Composite materials are now relatively common-place in airframe structures.

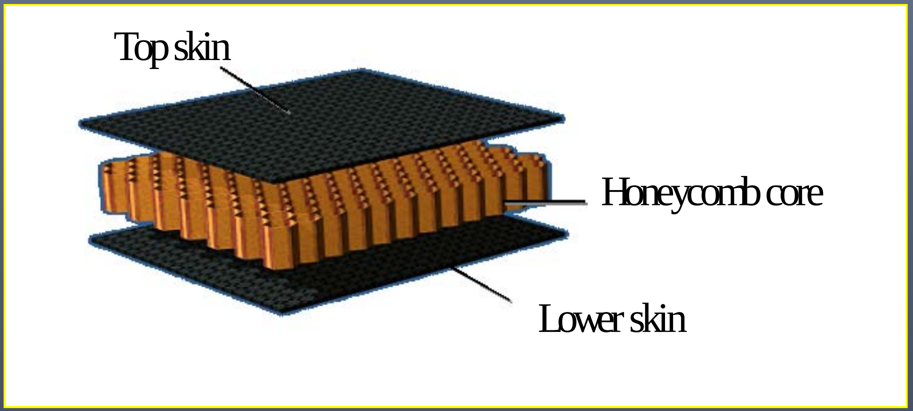
- Weight saved in the construction can be used to increase the aircraft's performance
- For fighter aircraft, this could be a greater rate of acceleration and stores carrying capability
- For commercial aircraft, this could be a reduction in relative fuel burn per nautical mile

Composite Construction

The material properties of a finished composite component are not always in the same in every direction.

- The component is said to be *anisotropic* (i.e. Strength is dictated by direction). Therefore, the design of the component will dictate it's properties in a given direction.

Not all composites are CFRP, sandwich panels may be constructed from CFRP with a paper of aluminium honeycomb core



Examples of Composite Applications

The Typhoon, A400M and A350 airliner introduce more use of composite in the primary structure

- Both A400M and A350 use composites for the front and rear wings spars and for the wing skins

- A400M is approximately 48% by weight made of Composite materials, whilst the Typhoon is 50% by weight

- The use of Composite materials allows enormous weight savings. The empty weight of a Typhoon is only 70% of that of the similar sized Tornado

Design Considerations

There are **two major** design considerations when using Composite materials

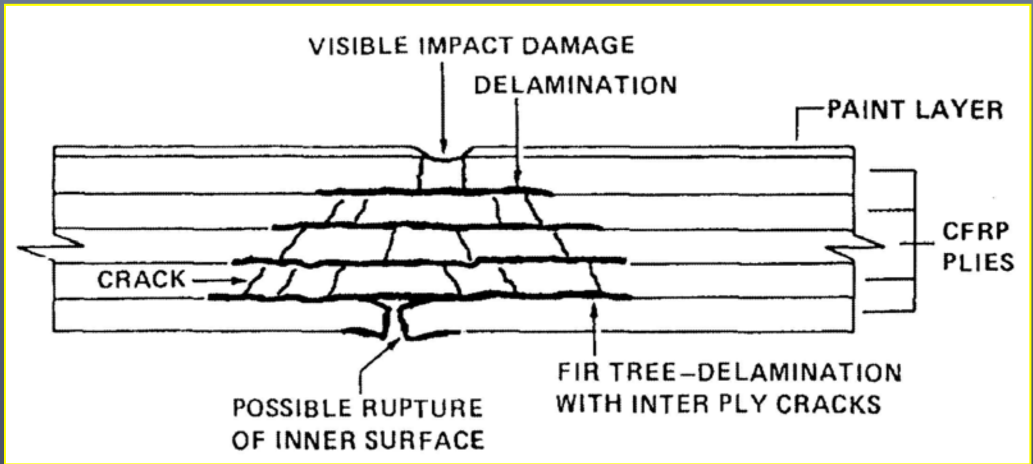
- Lightning Strike Protection: Carbon composite is a poor electrical conductor, so a bronze or copper mesh is added during manufacture
  - The addition of the mesh allows the electrical current from a lightning strike to be safely carried away and dissipated through the rest of the airframe
- Electromagnetic Shielding: Carbon composite is very poor at providing an electrical and magnetic shield for an airframe's electrical and electronic systems (Avionics)
  - EMC protection is required to ensure that these systems do not fail due to induced currents/signals from strong magnetic fields
  - Therefore, additional shielding needs to be added which adds to the weight, cost and complexity of the design

Composite Damage

Composites are much more tolerant to fatigue than metallic structures, but are not damage tolerant

- Therefore, it is important to be aware of damage that can be caused by knocks, collision damage and abuse

Initially, impact damage will cause what appears to be a small dent in the surface, but the damage may be more extensive below the surface with matrix cracking, fibre crushing and delamination over a wider area



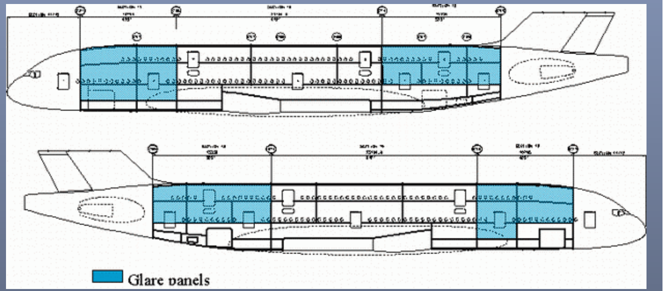
Composite Repair

The repair method selected depends largely on the type of structure and damage, but basically there are **3** types;

- **Bolted Repair:** involves machining off the damaged material and bolting a replacement plate (often metallic) in place.
- **Cold Bonded Repair:** involves repairing the damaged area with a matt of composite fibres, saturated in a cold-curing adhesive resin - Usually used in areas that have low strength.
- **Hot Bonded Repair:** involves using a fibre matt pre-impregnated with resin and the repair is cured by applying a controlled heat blanket.

Glass Reinforced Aluminium Laminate

Glass Reinforced Aluminium Laminate (GLARE) is used for the construction of panels



- Constructed from alternate layers of Aluminium sheets and Unidirectional glass fibre reinforcing sheets
- GLARE has a low susceptibility to corrosion as the glass layers act to retard moisture and also improve resistance to fire
- GLARE also has a better impact resistance that CFRP and is less susceptible to cracking than aluminium alloy
- Weight of GLARE is 10 – 30% lighter than aluminium, but is more expensive

Composite Advantages

The advantages of using Composites in airframe design are;

- They have a very high *Strength to Weight Ratio*
- They are good in Fatigue
- Composites are available in a wide range of forms
- They have a low resistance to RADAR and Radio Signals and are therefore ideal for radomes and antenna

Composite Disadvantages

However, there are some disadvantages to employing Composite materials:

- Composites are a highly specialist material and need special manufacturing and repair methods
- Their strength and stiffness is not the same in all directions and depends on method of manufacture
- They have poor electrical screening
- Damage is not immediately obvious and they require specialist Non-Destructive Testing (NDT) techniques to find damaged sections
- They can absorb water (especially honeycomb panels)

Conclusions

Modern airframes employ a variety of different materials in their design and the designer must choose the material with the correct properties.

Therefore thorough under-standing of material properties is needed to ensure that the designed components are safe and reliable.

You should now have an understanding of the ***'materials'*** that make up an airframe, as well as how material properties influence the design.

Any Questions?

Questions

Here are some questions for you;

1. What does the term **CFRP** stand for?

2. What is Fatigue?

3. What are the two ***major design considerations*** involved in the use of Composite materials?

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