Summary

Progress in structural materials for aerospace systems

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Introduction

In the old times, only performance and money were the only characteristics of a successful aircraft. Nowadays, various metrics are involved like good customer value, minimal environmental impact, scalability, application area etc. Due to these new metrics, the selection of material has become a more crucial task. A designer not only needs to keep in mind the light weightiness and strength of the material but also recyclability, emissions during manufacturing, quantity available on the earth. The four critical objectives while designing a product are:

1. Improving performance: Materials capability and design methodology. E.g. Honeycomb construction.
2. Reducing ownership cost: Scaling the production and availability of raw materials.
3. Extending system life: Robust and efficient engineering
4. Reducing environmental impact: recyclability and production emission

The selection of proper material is the key to achieve all these objectives.

Materials for aerospace systems

As discussed in the introduction, strength to weight ratio was the prime driver for material selection for both engines and aircraft in the old times. The transition from internal combustion piston engines to turbines resulted in a significant change in weight constraints. The performance of early turbine engines was limited because of the thermal sturdiness of materials.

The evolution of aircraft and the role of materials

With the development of high speed and load aircrafts, the need for better structural materials has been increased drastically. High-speed planes need better skin material to protect them from frictional heating. Perhaps the most sophisticated aircraft ever built in the western world is the SR-71 Blackbird which had an all Ti alloy skin and was capable of speeds above Mach 3. In addition to this, it told us that it is tough to above Mach 2 for commercial aircrafts, especially with aluminium skin. Designers use the algorithm in Fig1 to improve performance and reduce operating costs for aircraft and spacecraft. Using this type of program, a designer can determine the actual potential weight savings.

Evolutionary improvement of aluminium alloys for aircraft

Although polymer matrix composites are being used in modern commercial aircraft, e.g. for the fin of the Airbus A310, the horizontal stabiliser of the Airbus A340, and the Boeing 777, aluminium alloys have remained the materials of choice for the airframe of most commercial aircraft. Fe and Si's impurities from coarse constituents in 2XXX, 7XXX, and 8XXX aluminium alloys result in lower fracture toughness. Low Fe and Si levels, a good knowledge of complex phase diagrams and tight controls on composition can be used to produce a good balance of strength, fracture toughness, and fatigue crack growth resistance. The two major passenger aircraft manufacturers (Airbus and Boeing) have recently introduced aircraft which utilised evolutionary improvements of older materials.

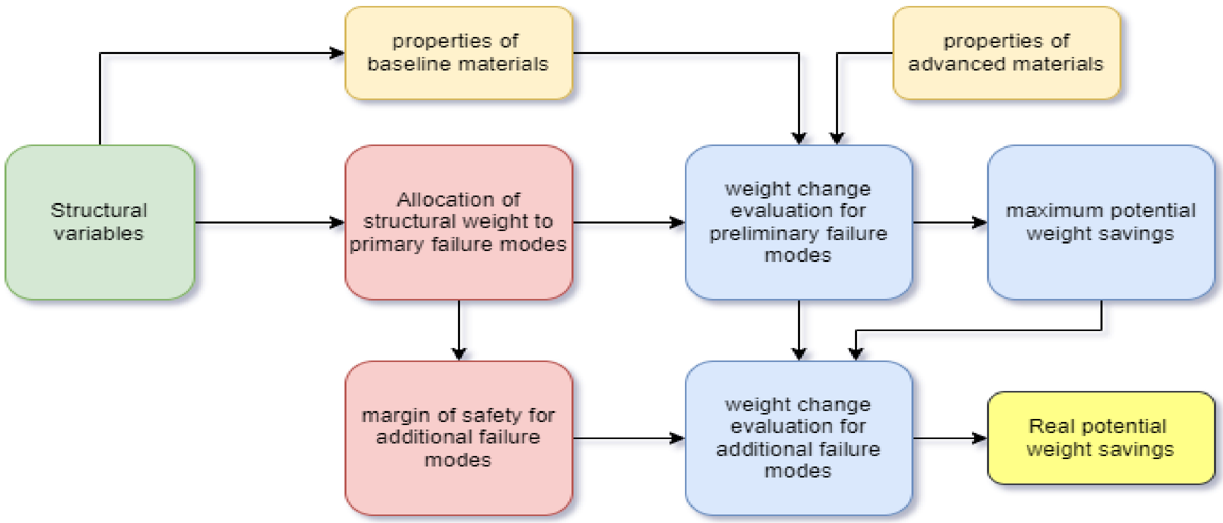

Fig1: Flow chart showing the order of events in computer-aided materials selection.

Lighter weight, higher stiffness materials for aircraft

Aluminium-Lithium alloys are used to create lightweight materials. Each weight per cent of lithium lowers the density of aluminium by approximately 3% and increases the modulus by approximately 6%. The first of the newer generation Al-Li alloys was Weldalite 049 (2094), which can attain a yield strength as high as 700 MPa and an associated tensile elongation of 10%.

Improved Al base materials for newer systems

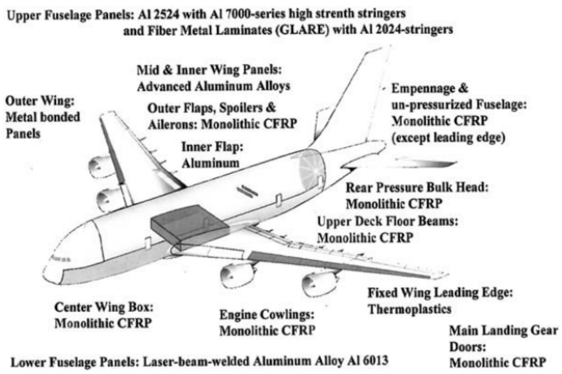

Fig 2: Schematic depicting materials chosen for use in the new, very large Airbus A-380

The final materials selection is displayed in Fig 2 and includes advanced aluminium alloys, carbon fibre reinforced plastics (CFRP), fibre metal laminates (GLARE) and glass thermoplastics. Note that even for this advanced aircraft, the majority of the weight of the airframe is still made of aluminium (66%). Various innovations have been observed to develop new materials. However, Airbus considers that a more evolutionary approach is preferred since past experience has shown that almost every new technology has some initial technical problems. However, the new materials development will continue to be monitored for possible mid-term candidates for continuous improvement with respect to weight savings, possibly replacing 2024 and 2524.

New methods for Al alloy design

Instead of a purely empirical, trial and error approach, we are using modelling and simulation is used to optimize the manufacturing process. Often times the phase diagrams for a complex alloy system have not been determined and must be calculated using programs such as CALPHAD (CALculation of PHAse Diagrams). This method is an approach to establishing equilibria among phases, through thermodynamic modeling of the individual phases based on the idea of phase competition in a system. The phases are modelled according to the phase stabilities, measured thermodynamic properties, and measured transit points.

Ti alloy usage in aircraft

Ti alloys are mainly used for a high-speed military airplane like SR-71, heavily loaded structure like B1-B bomber and the landing gear beam in the Boeing 747, helicopter rotors. Ti alloys are also a very good alternative to high strength steel.

Evolution of propulsion systems and the role of materials

A modern subsonic aircraft engine for a passenger or transport aircraft consists of discrete sections or modules: fan, low pressure compressor (LPC), high pressure compressor (HPC), combustor, high pressure turbine (HPT) and low pressure turbine (LPT). The USFAA and EJAA have explicit criteria for certifying an airplane direct overwater routes. The rating is called Extended Twin-engine Operations (ETOPS in minutes), higher ETOPS ratings enable a longer the over-water portion of the total flight.

Evolutionary improvement in Ti alloys for aircraft engines

A process known as hearth melting is being used to produce much of the rotor grade material for jet engines. The heat extraction from the hearth is carefully managed to ensure that a thin layer of solid Ti alloy (called a skull) remains and is in direct contact with the hearth. Some other methods are also used to clean the defects in the material.

Improved Ti alloys for new propulsion systems

By comparison to Al alloys, there has been less effort devoted to developing and commercialising new Ti alloys. In addition to conventional a + b Ti alloys, a lot of effort has been devoted to developing Ti-based intermetallic compounds for high-temperature applications. These compounds are based on the phases Ti3Al, Ti2AlNb and TiAl. However, Market pull and customer value will be the determinant here, not materials technology.

Evolutionary improvement in Ni alloys for aircraft engines

At temperatures above ~550 °C, Ni-base alloys are used instead of Ti alloys. A highly disciplined powder handling process is essential to avoid the accidental incorporation of unwanted contaminants that can have deleterious effects on fatigue behaviour. A typical processing sequence is Inert gas atomisation to form powder; Screening of the powder to a predetermined maximum powder particle size, typically 270 mesh (44 µm); Vacuum degassing of the powder; Placing the powder in an extrusion can; Extruding the powder into a billet using an extrusion ratio that assures full density; Forging the billet into a final forged part, often by an isothermal, hot die forging process.

Conclusion

In aerospace technology, materials play a crucial role. From enhancing the propulsion system to reducing the environmental impact, the selection of appropriate material is essential. Currently, in the market, Aluminium alloys are the most prominent structural materials, after this, Ti alloys are also used significantly and for particular purposes. Various researches are being conducted in these areas to find more structurally stable and sturdy materials. However, these new innovations use simulation and modelling to be economically stable, and most of these are firstly tested in less danger prone fields.

1. Material Strength: The strength of a material is defined as the ability to resist the load without plastic deformation or any failure. So it is mainly a measure of the load to deformation ratio of the material.

    E.g. The strength of new aluminium alloys kept increasing with time linearly

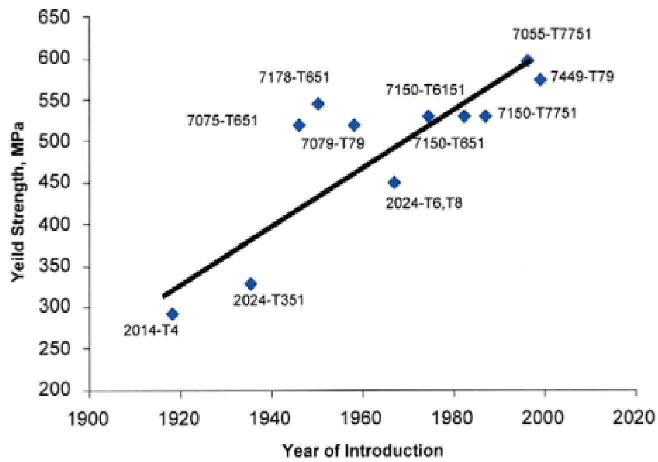

    Fig: Plot of yield strength for new Al alloys as a function of the year of introduction

2. Material stiffness: Material stiffness is described as the measure of the ratio of shear stress to shear strain when the material is deformed by a force parallel to its surface.

    E.g. The plot below shows that the stiffness of aluminium alloys initially remained constant till ~1950, and after that, it also started increasing with time but with a small slope.

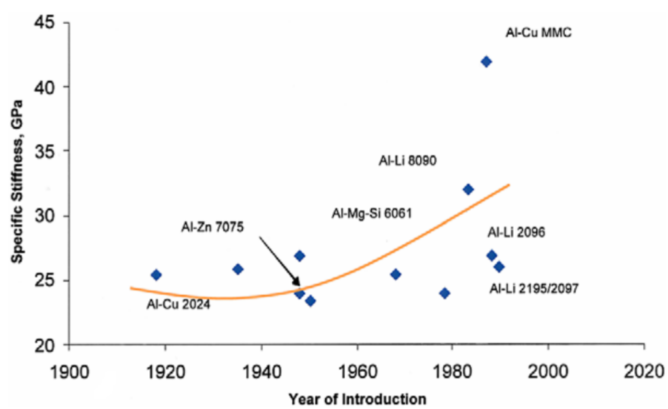

    Fig: Plot of the density normalised modulus of Al alloys as a function of the year of introduction.

3. Toughness: Toughness is the ability of a material to absorb energy and plastically deform without fracturing. In other words, toughness is the amount of energy per unit volume that a material can absorb before rupturing.

    E.g. This schematic is different from others. It shows fracture toughness vs strength. Consider 2524-T3 improved and gave more toughness at the same strength while 2523-T351 improved to give more strength at the same fracture toughness. So all over the new performance of the material increased.

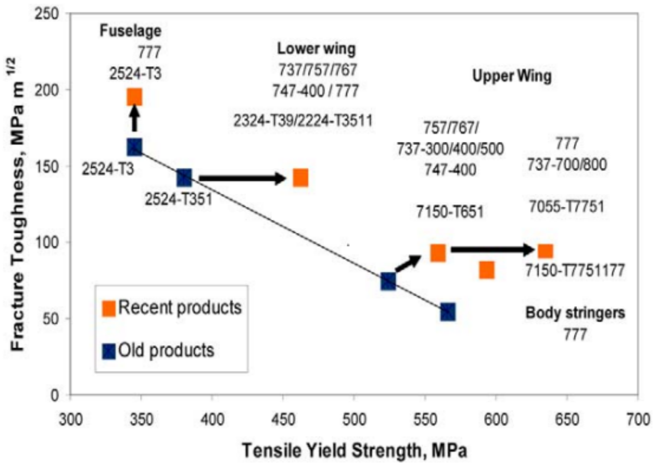

Fig: Plot showing the improvements in strength-toughness combinations of some newer Al alloys

4. Bauschinger effect: The phenomenon by which plastic deformation of a metal increases the yield strength in the direction of plastic flow and decreases the yield strength in the opposite direction.
5. Creep: Creep is a structural element's increased strain or deformation under a constant load. Depending on the construction material, structural design, and service conditions, creep can result in significant displacements in a structure.

   E.g. This shows that the creep strain of C416<C415<CM.001 for all the time. Also, CM.001 withstand for the highest time.

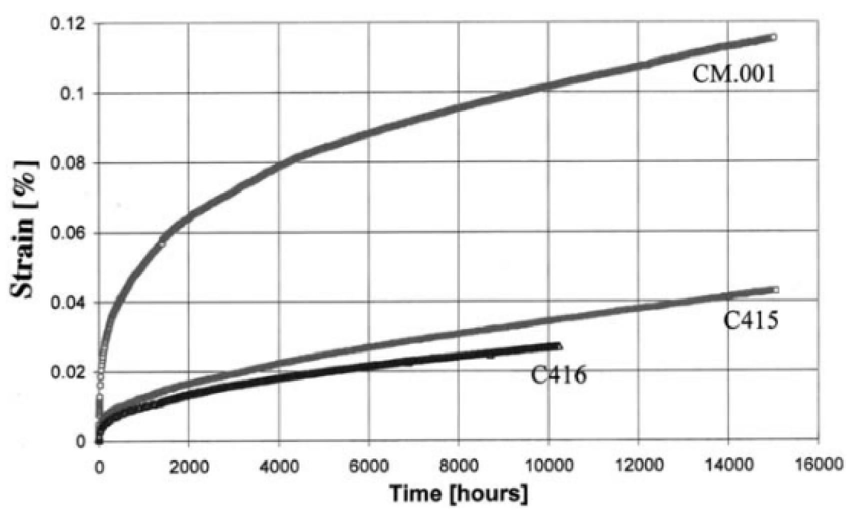

Fig: Creep strain vs time plots for three Al alloys. Tests conducted at 107°C with a load of 207 MPa