MODULE - 2

Non-ferrous materials in Aircraft Construction

COURSE CODE: 21AE32

Heat Treatment Process

Definition of terms

1. **Annealing :** Annealing is the process of heating steel above the critical range, holding it at that temperature until it is uniformly heated and the grain is refined, and then cooling it very slowly.
2. **Normalizing :** Normalizing is similar to annealing, but the steel is allowed to cool in still air - a method that is somewhat faster than annealing cooling. Normalizing applies only to steel.
3. **Heat Treatment :** Heat treatment consists of a series of operations which have as their aim the improvement of the physical properties of a material.
4. **Hardening :** Hardening of steel is done by heating the metal to a temperature above the critical range and then quenching it.

5. Quenching: Quenching is the immersion of the heated metal in a liquid, usually either oil or water, to accelerate its cooling.

6. Tempering: Tempering is the reheating of hardened steel to a temperature below the critical range, followed by cooling as desired. Tempering is sometimes referred to as "drawing".

7. Carburizing: Carburizing is the addition of carbon to steel by heating it at a high temperature while in contact with a carbonaceous material in either solid, liquid, or gaseous form.

8. Case-hardening: Casehardening consists of carburizing, followed by suitable heal treatment to harden the metal.

Aluminium and its alloys

- Aluminium became an important structural material, especially after A. Wilm had discovered the age hardening capability of AI-Cu alloys in 1906.
- Nowadays high strength aluminium alloys are still the most important structural materials for aircraft.
- Pure aluminium is a very soft metal which cannot be used for structural applications.
- When alloyed with certain other elements, it gains strength by solid solution hardening, but the most effective strengthening mechanism is age or precipitation hardening.
- Commercial high strength aluminium alloys mostly contain two or more primary alloying elements (copper, zinc, magnesium, lithium), at least one minor alloying element (manganese, chromium, zirconium), plus various impurities (iron, silicon).
- Aluminium alloys rapidly form a protective oxide layer of alumina on their surface, making them quite corrosion resistant.

- The Aluminium Association (AA) of the United States has introduced a four-digit numerical system for designating wrought aluminium and aluminium alloys.
- This system has been accepted by most countries and is now called the International Alloy Designation System (lADS).
- The first of the four digits indicates the alloy group.
- The last two digits are arbitrary numbers identifying the specific alloy in the alloy group, except group for I XXX where they indicate the aluminium purity.
- The second digit indicates modifications of the original alloy, e.g. 2124 and 7475 are higher purity versions of 2024 and 7075, respectively.
- Alloys which are still experimental have the letter X preceding their designation number.
- The high strength age-hardenable aluminium alloys are found in the following alloy groups:
    a. The AI-Cu and AI-Cu-Mg alloys in the 2XXX group
    b. A few AI-Mg-Si alloys in the 6XXX group
    c. The AI-Zn-Mg-Cu alloys in the 7XXX group
    d. Lithium containing alloys with lithium as the major alloying element in the 8XXX group

Designation	Al content or major alloying elements
1XXX	99.00% aluminimum2)
2XXX	copper
3XXX	manganese
4XXX	silicon
5XXX	magnesium
6XXX	magnesium and silicon
7XXX	zinc
8XXX	lithium or others
9XXX	unused

- In order to specify the mechanical properties of an alloy, an Aluminium Association temper designation system is used.
- The temper designation system for heat-treatable aluminium products employs the letter T followed by a number from 1 to 10 for the basic alloy conditions.
- Often additional digits are added to the basic designation in order to give a more detailed description of the respective condition.

Design ation.	**Description**
T3	• Indicates that a product is solution heat treated, cold worked and naturally aged. • It applies to alloys which achieve a stable condition during natural aging and whose strength is improved by cold deformation.
T4	• Designates a product that is solution heat treated and naturally aged. • It applies to products which achieve a stable condition during natural aging and which are not (or cannot) be cold worked after solution heat treatment.
T6	Designates a product that is solution heat treated and artificially aged.
T7	• Means that a product is solution heat treated and stabilized. • It applies to products that are over-aged during artificially aging to provide specific characteristics such as improved resistance to stress corrosion.
T8	Indicates that a product is solution heat treated, cold worked and artificially aged.

Alloy	Al	Cu	Mg	Zn	Mn	Cr	Zr	Fe	Si	others
2014	Bal	3.9-5.0	0.2-0.8	0.25	0.4-1.2	0.1	-	0.7	0.5-1.2	
2024	Bal	3.8-4.0	1.2-1.8	0.25	0.3-0.9	0.1	-	0.5	0.5	
2324	Bal	3.8-4.4	1.2-1.8	0.25	0.3-0.9	0.1	-	0.12	0.1	
2219	Bal	5.8-6.8	0.02	0.1	0.2-0.4	-	0.1-0.25	0.3	0.2	
2618	Bal	1.9-2.7	1.3-1.8	0.1	-	-	-	0.9-1.3	0.1-0.25	0.9-1.2 Ni
X2095	Bal	3.9-4.6	0.25-0.6	0.25	0.1	-	0.04-0.18	0.15	0.12	0.25-0.6 Ag 1-1.6 Li
6013	Bal	0.6-1.1	0.8-1.2	0.25	0.2-0.8	0.1	-	0.3	0.6-1.0	
7075	Bal	1.2-2.0	2.1-2.9	5.1-6.1	0.3	0.18-0.28	-	0.5	0.4	
7475	Bal	1.2-1.9	1.9-2.6	5.2-6.2	0.06	0.18-0.25	-	0.12	0.1	
7050	Bal	2.0-2.6	1.9-2.6	5.7-6.7	0.1	0.04	0.08-0.15	0.15	0.12	

Alloy Temper	Product	YS MPa	UTS MPa
2014-T6	sheet	400	455
2024-T361[1]	sheet	330	440
2324-T39	plate	386	455
2219-T81	sheet	345	455
		421[2]	572[2]
2618-T61		372	441
X2095-T8	extrusion	696	715
6013-T6	sheet	324	359
7075-T6	sheet	469	538
7075-T6[1]	sheet	427	496
7475-T61	sheet	496	552
7475-T7351	plate	393	475
7050-T73651	plate	455	510

Aircraft	Upper Wing Skin	Lower Wing Skin	Fuselage Skin
BAe 146	7075-T6	2024-T351	2024-T3[1]
A300/310	7075-T651	2024-T351	2024-T3[1]
A320/330/340	7150-T651	2024-T351	2024-T3[1]
			-T351[1]
			-T42[1]
B747	7075-T651	2024-T351	2024-T3[1]
B757/767	7150-T651	2324-T39	2024-T3[1]
B777	7055-T7751	2324-T39	2XXX[2]-T3[1]
C-5B	7175-T73	7175-T73	7475-T6[1]

- 2024-T3 - It has high ductility, excellent fatigue crack propagation resistance, and high fracture toughness

Magnesium alloys

- Magnesium is the lightest of the structural metals available for aircraft construction.
- Pure magnesium weighs only 65% as much as aluminium.
- It is a silvery white metal that is relatively soft, and does not have the strength or other properties required for structural use.
- Pure magnesium has the following properties:

Specific gravity	1.74	Mean coefficient of thermal expansion, per inch per °F.(32°–750°F.)	0.0000166 inches
Density	0.064 lb./cu. in.	Modulus of elasticity	6,500,000 p.s.i.
Melting point	1204°F.		
Flame temperature	8760°F.		
Electrical conductivity:			
Volume basis	38% of copper		
Mass basis	197% of copper		

- Magnesium is commonly alloyed with aluminium, zinc, and manganese, to create usable structural materials.
- The light weight and relatively high strength of magnesium alloys results in a strength/weight ratio that is very attractive in aircraft design.

- There are many places in aircraft construction, such as fairings, ducts, doors, brackets, bulkheads and partitions, and similar locations, where strength is secondary and a minimum thickness of material is all that is necessary.
- Magnesium alloys are non-sparking and nonmagnetic.
- These alloys are very poor as regards toughness and notch sensitivity in fatigue, and some alloys are susceptible to stress-corrosion cracking.
- Suitable heat treatment, good design, and the proper choice of alloy for a given application will minimize these disadvantages.
- The common impurities found in magnesium alloys are iron, nickel, and copper.
- These impurities affect the corrosion resistance of the alloy and must be held to a minimum.

Titanium alloys

- Titanium the so-called wonder metal.
- Titanium is extremely active at elevated temperatures and will combine with practically anything it comes into contact with.
- Alpha titanium: hexagonal close-packed crystal structure
- Beta titanium: body-centered cubic crystal structure.
- The physical properties of pure titanium is as given in the table:

Physical Properties	*Titanium*
Atomic Number	22
Atomic Weight	47.9
Crystal Structure	Alpha—H.C.P. (below 1625°F.) Beta–B.C.C. (above 1625°F.)
Transformation	1625°F.
Density	4.5 gm. per c.c.
Melting Point	3272°F.
Linear Coefficient of Thermal Expansion	4.3 X 10^{-6}/°F.
Specific Heat	0.129 Cal./gm./°C.
Electrical Conductivity	3.5% I.A.C.S.*
Magnetic	Para
Electrode Potential	1.75

Advantages	Disadvantages
All-Alpha	
• Useful strength to almost 1200°F. • Resistant to air contamination to 2000°F, permitting higher forging temperature. • No embrittling heat treatment response. • Weld ductility and strength comparable to that of base metal. • Tough at low temperatures.	• Sheet bend ductility not as good as alpha-beta alloys, considerably poorer than beta alloys. • Requires more power than alpha-beta alloys for hot working.
Combined Alpha-Beta	
• Double the strength of unalloyed titanium and about as strong below 600°F, as all-alpha and all-beta. • Good ductility, including bend. • Forging, rolling and forming easier than alpha and beta alloys (beta has better bend ductility). • Relatively simple to produce in quality. • Heat-treatable to high strengths.	• Poorer weld ductility than alpha. • Temperature ceiling for useful strength about 800°F.

Advantages	Disadvantages
Heat Treatable Beta	
• Quenchable to give medium strength with high ductility. • Can be heat-treated to higher strength (with some loss in ductility) after little fabrication. • Elevated-temperature properties similar to alpha-beta alloys.	• Embrittled by 24 to 96 hr. at 350 to 800°F. • Control of composition critical. • Restricted to parts that can be heat treated after fabrication or require little forming after heat-treating. • Requires relatively high content of strategic alloying materials.
Non-Heat Treatable Beta	
• Excellent ductility, particularly bend. • High strength useful to approx. 1000°F. • Does not require heat treatment for high strength. • Good weldability with some composition.	• Greater spring back in forming. • Uses higher content of strategic alloying materials than unstable beta. • Relatively high density.

Steel and its alloys

- The basis of all steel is iron which, when combined with carbon and other elements in varying amounts, gives a wide range of physical properties.
- Exact control of the alloying elements is essential to obtain a high-grade steel for aircraft use.
- Due to the large number of elements that will combine with iron, an infinite number of steels is obtainable.
- In order to classify the better-grade steels used in automotive and aircraft work, the Society of Automotive Engineers has formulated a numerical index system which is generally used.

Type of Steel	Numerals (and Digits)
Carbon steels	1xxx
Plain carbon	10xx
Free cutting (screw stock)	11xx
Manganese steels	13xx
Nickel steels	2xxx
3.50% nickel	23xx
5.00% nickel	25xx
Nickel-chromium steels	3xxx
1.25% nickel; 0.60% chromium	31xx
1.75% nickel; 1.00% chromium	32xx
3.50% nickel; 1.50% chromium	33xx
Corrosion- and heat-resisting steels	30xxx
Molybdenum steels	4xxx
Carbon molybdenum	40xx
Chromium molybdenum	41xx
Chromium-nickel molybdenum	43xx
Nickel molybdenum; 1.75% nickel	46xx
Nickel molybdenum; 3.50% nickel	48xx
Chromium steels	5xxx
Low chromium	51xx
Medium chromium	52xxx
Corrosion- and heat-resisting	51xxx
Chromium-vanadium steels	6xxx
1% chromium	61xx
Nickel-chromium-molybdenum steels.	8xxx
0.55% nickel; 0.50% chromium: 0.20% molybdenum	86xx
0.55% nickel; 0.50% chromium; 0.25% molybdenum	87xx
Silicon-manganese steels	9xxx
2% silicon	92xx

Effect of individual elements

1. **Carbon:** Carbon is by far the most important constituent of steel. It combines readily with iron to form iron carbide, which is a compound known as cementite. It is largely due to the quantity and behaviour of this compound that steels can be heat-treated to various degrees of strength and toughness.
2. **Manganese:** Its primary purpose is to deoxidize and desulfurize the steel to produce a clean, tough metal.. This excess magnitude exists as manganese carbide which has characteristics in hardening and toughening the steel.
3. **Silicon:** A small amount of silicon improves the ductility of the metal. Its main purpose, however, is to produce a sound metal
4. **Sulfur:** The presence of sulfur renders steel brittle at rolling or forging temperatures.
5. **Phosphorus:** Phosphorus is believed responsible for "cold shortness" or brittleness when the metal is cold.

6. **Nickel:** . The addition of nickel to steels increases the strength, yield point, and hardness without materially affecting the ductility.
7. **Chromium:** Chromium imparts hardness, strength, wear resistance, and corrosion resistance to steel. It also improves the magnetic qualities to such an extent that chromium steel is used for magnets.
8. **Molybdenum:** It improves the homogeneity of the metal and reduces the grain size. It also increases the elastic limit, the impact value, wear resistance, and fatigue strength.
9. **Vanadium:** Improves the grain structure and fatigue strength. Vanadium also increases the ultimate strength, yield point, toughness, and resistance to impact, vibration, and stress reversal.
10. **Tungsten:** "High-speed steel" is a tungsten-chromium steel used for tools which will retain their cutting edge even when heated to dull redness by working.
11. **Titanium:** Titanium is often added in small quantities to corrosion resisting steel to reduce the embrittlement at the operating temperatures of exhaust stacks and collectors.

Plain carbon Steels

- The classification of iron and steel is based on the percentage of carbon present.
- The generally accepted classification is as follows:

Wrought iron	Trace to 0.08%
Low carbon steel	0.10% to 0.30%
Medium carbon steel	0.30% to 0.70%
High carbon steel	0.70% to 2.2%
Cast iron	2.2% to 4.5%

- The addition of a metallic alloying element to plain carbon steels results in the formation of a new alloy steel with wholly different properties.
- The carbon content of alloy steels is of prime importance but varying properties can be obtained by adding an alloy.
- The metals commonly used as alloys in steel are nickel, chromium, molybdenum, vanadium, and tungsten.

Corrosion resisting steels

- Corrosion resisting steels are not fully resistant to all corrosive agents.
- Their corrosion resistance depends upon their own physical state as well as the temperature and concentration of the particular corrosive agent.
- In aircraft design the most severe corrosive agent to be guarded against is salt water.
- Specimens are rated A, B, C, or D-A representing the best resistance and D an unacceptable condition.

Copper alloy

- COPPER, brass, and bronze have a limited use in aircraft construction.
- They do have important specialized applications, however, such as bearings and fuel and oil lines.
- Copper wire is used throughout the electrical system.
- In general these metals are corrosion resistant, nonmagnetic, fairly strong, and good conductors of electricity.

Copper Tubing

- Copper tubing is very generally used for fuel and oil lines.
- The copper used in the manufacture of this tubing must contain at least 99.90% copper.
- The tubing is purchased in the soft annealed condition and it is seamless drawn.
- In the purchased condition or after annealing it has the following physical properties:

Ultimate tensile strength (p.s.i.)	32,000
Yield point (p.s.i.)	6,000
Elongation (%)	52%
Rockwell hardness	63 (B-1/8-100)

Copper-Silicon-Bronze Tubing

- This tubing is considerably stronger than pure copper tubing and has largely superseded it for fuel, oil, water, and air lines.
- This tubing can be annealed at a temperature of 1000-1000°F, if required after severe forming and bending.

Copper Wire

A soft copper wire is used as a locking wire in aircraft construction. It is drawn from pure copper and has a tensile strength approaching 40,000 PSI and an elongation of 25%.

Beryllium copper

This material is a high-strength, heat-treatable non-magnetic alloy available as bar, rod, sheet, strip, and wire.

BRASS

- Brass is a copper alloy consisting of a solid solution of zinc in copper.
- In addition to zinc and copper, brasses sometimes contain a small amount of aluminium, iron, lead, manganese, magnesium, nickel, phosphorus, or tin.
- Brass with a zinc content of 30% to 35% is very ductile, and with 45% zinc content it has a relatively high strength.
- Brasses with a zinc content up to 37% are in so-called "alpha solution," while above that percentage a "beta solution" condition exists.
- It is the difference between these two conditions that accounts for the ductility of the low-zinc brass and the strength of the high-zinc brass.
- Alpha-solution brass can only be annealed, but beta-solution brass can be increased in strength by heat treatment.

Selection of Aerospace Material:

- Selecting the best material is an important task for the aerospace engineer.
- The success or failure of any new aircraft is partly dependent on using the most suitable materials.
- Cost, flight performance, safety, operating life and environmental impact from engine emissions are dependent on the types of materials.
- The selection of materials is performed during the early design phase of aircraft, and has a lasting influence which remains until the aircraft is retired from service.

Selection of Aerospace Material:

- Key requirements and factors in the selection of materials are

1. Costs
2. Availability
3. Manufacturing
4. Density
5. Mechanical properties
6. Fatigue durability
7. Damage tolerance
8. Environmental durability
9. Thermal properties
10. Electrical and magnetic properties

Selection of Aerospace Material:

Cost:

1. Purchase cost
2. Processing costs, including machining, forming, shaping
3. Heat treatment costs
4. In-service maintenance costs, including inspection and repair costs
5. Recycling and disposal costs

The cost of aerospace materials must be acceptable to the aircraft operator, and obviously should be kept as low as possible.

Selection of Aerospace Material:

Availability:

There must be a plentiful, reliable and consistent source of materials to avoid delays in aircraft production and large fluctuations in purchase cost.

Manufacturing:

It must be possible to process, shape, machine and join the materials into aircraft components using cost-effective and time-efficient manufacturing methods.

Density:

Materials must be lightweight for aircraft to have good manoeuvrability, range and speed together with low fuel consumption.

Selection of Aerospace Material:

Mechanical properties:

High stiffness, strength and fracture toughness to ensure that structures can withstand the aircraft loads without deforming excessively (changing shape) or breaking.

Fatigue durability:

Aerospace materials must resist cracking, damage and failure when subjected to fluctuating (fatigue) loads during flight.

Damage tolerance:

Aerospace materials should not break after being damaged (cracks, delaminations, corrosion) from bird strike, lightning strike and the many other damaging events experienced during routine operations.

Selection of Aerospace Material:

Environmental durability:

- Aerospace materials must be durable and resistant to degradation in the aviation environment.
- This includes resistance against corrosion, oxidation, wear, moisture absorption and other types of damage caused by the environment which can degrade the performance, functionality and safety of the material.

Thermal properties:

- Aerospace materials must have thermal, dimensional and mechanical stability for high temperature applications, such as jet engines and heat shields.
- Materials must also have low flammability in the event of aircraft fire.

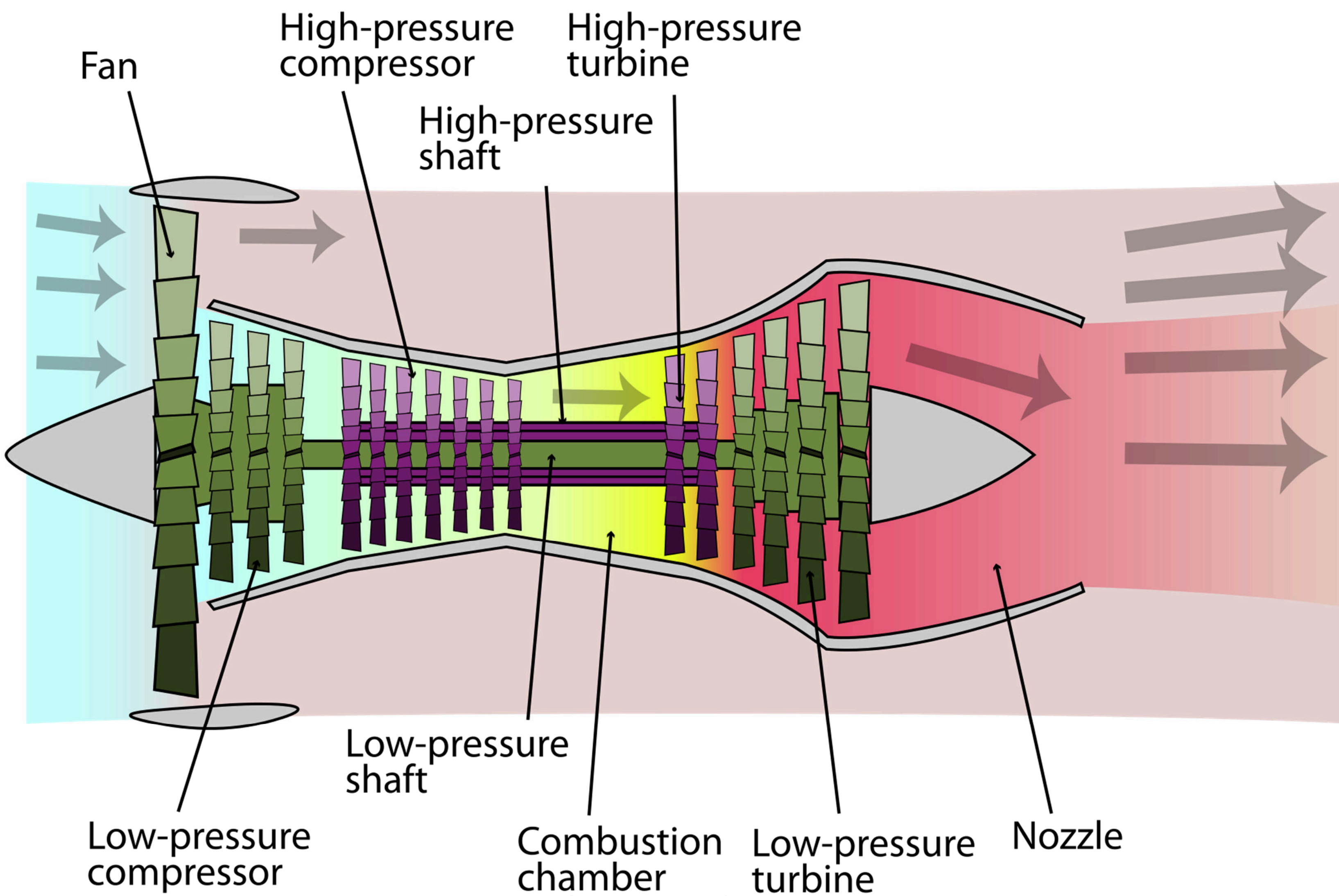
Selection of Aerospace Material:

Electrical and magnetic properties:

- Aerospace materials must be electrically conductive to dissipate the charge in the event of lightning strike.
- Aerospace materials must have low electromagnetic properties to avoid interfering with the electronic devices used to control and navigate the aircraft.
- Materials used in the skin of stealth military aircraft must have the ability to absorb radar waves to avoid detection.

Materials used in aircraft engines:

Engine structure (turbofan):



Materials used in aircraft engines:

Fan:

This typically does not get very hot (<150 °C) so aluminum, titanium, or stainless steel are all suitable for the fan blades. Most engines use titanium because it has a high strength-to-weight ratio, is corrosion and fatigue resistant, and would be able to withstand the impact of a bird strike.

Materials used in aircraft engines:

Compressor section:

- The pressure of the air can be raised up to 30 times and the temperature, depending on the number of stages in the compressor, can rise to 1000 °C.
- Here the materials must have high strength at high temperatures; must resist fatigue, cracking, and oxidation; and also must resist “creep.”
- Very high- temperature alloys are called super alloys and are generally nickel, cobalt, or iron-based alloys.
- Aluminium and/or titanium are added for strength, and chromium, as well as rare earth elements like yttrium, are added to improve corrosion resistance.

Materials used in aircraft engines:

Combustion chamber:

- Temperatures can exceed 1800 °C and again super alloys are used, but without the titanium or aluminium.
- Instead, refractory metals such as tungsten, molybdenum, niobium, tantalum, and rhenium are often added to a super alloy - high resistance to heat, corrosion, and wear.
- Ceramics and ceramic-metal mixes are also used here because of their high heat resistance.
- They have very high melting points and don't require the cooling systems like those needed to keep metals from melting so they make for lighter, less complicated engine parts.
- Disadvantage is that they tend to fracture under stress, so trend is to create new ceramics composites that incorporate other materials to improve properties.

Materials used in aircraft engines:

Turbine:

- The first set of turbine blades are in the highest pressure, hottest part of the gas flow and are generally made of nickel-based super alloy or ceramic blades.
- Unheated outside air is circulated through channels inside of the turbine blades to keep them from melting in this extreme environment.
- The blades lower pressure turbine are made of iron-based super alloy or even stainless steel.

Materials used in aircraft engines:

Exhaust:

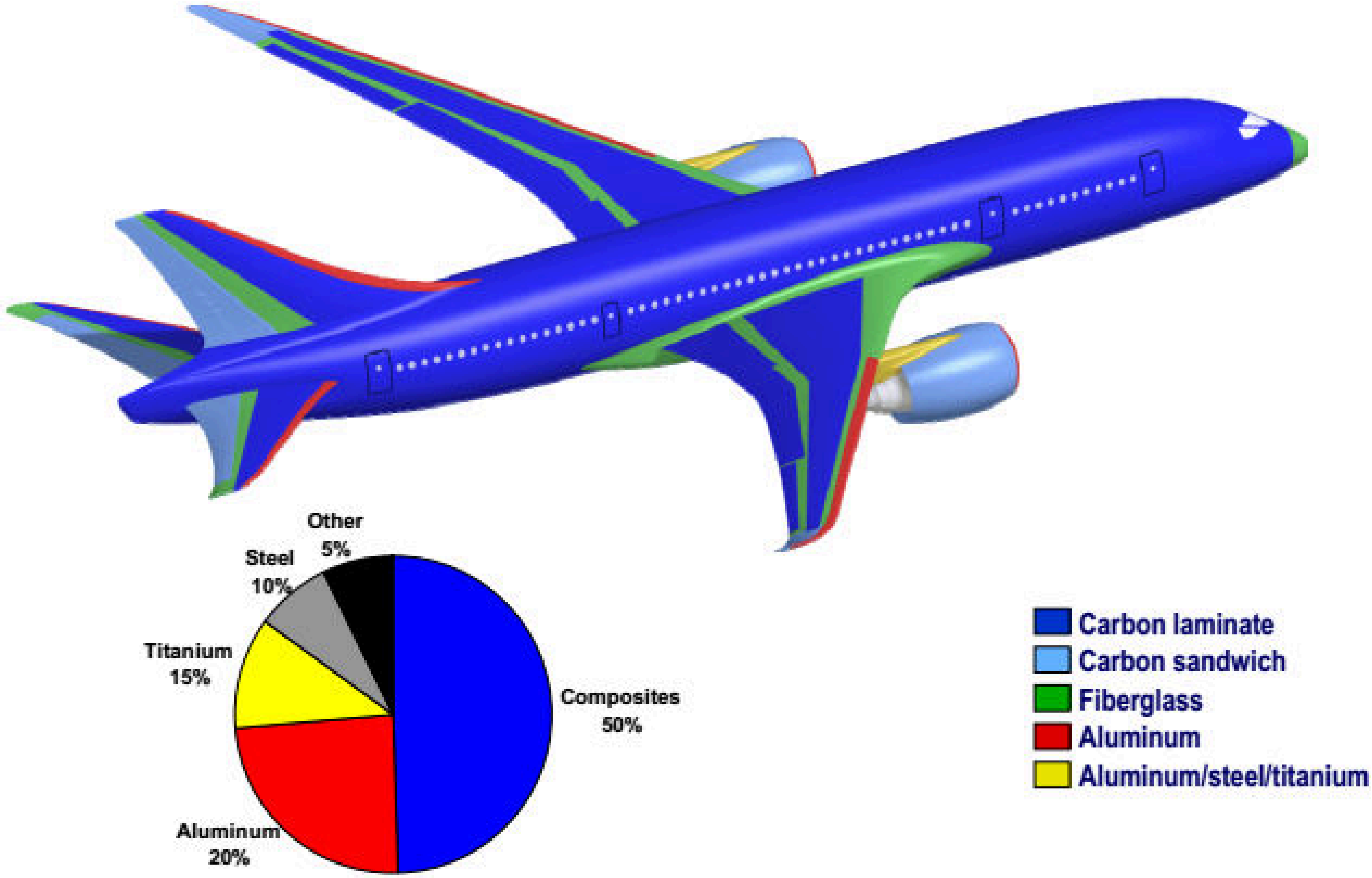
- Inconel and stainless steel alloys. The Inconel [nickel-chromium-iron] alloys are frequently used in turbine engines because of their ability to maintain their strength and corrosion resistance under extremely high temperature conditions.

Casing:

- Although it need not withstand high temperatures like the core of the turbine, the materials here need to be strong enough that if a blade were to break off it would be contained within the casing and not enter the wing or cabin of the aircraft and cause further damage.
- Aluminum or some polymer matrix materials are used as engine casings.

Materials used in aircraft structures:

Boeing 787:



Materials used in aircraft structures:

Boeing 787:

- Jets made of composites require far fewer parts, so there's less to bolt together.
- Since these plastics weigh less than aluminium, the planes should burn less fuel - together with improved engines, 20% drop in fuel costs.
- Improve passenger comfort - superior strength of the composite fuselage will allow the passenger cabin to withstand higher pressurization.
- It's easier to control cabin temperature, humidity, and ventilation.
- Maintenance costs will be 30% lower than for aluminium planes - corrosion and fatigue benefits are going to be astounding.