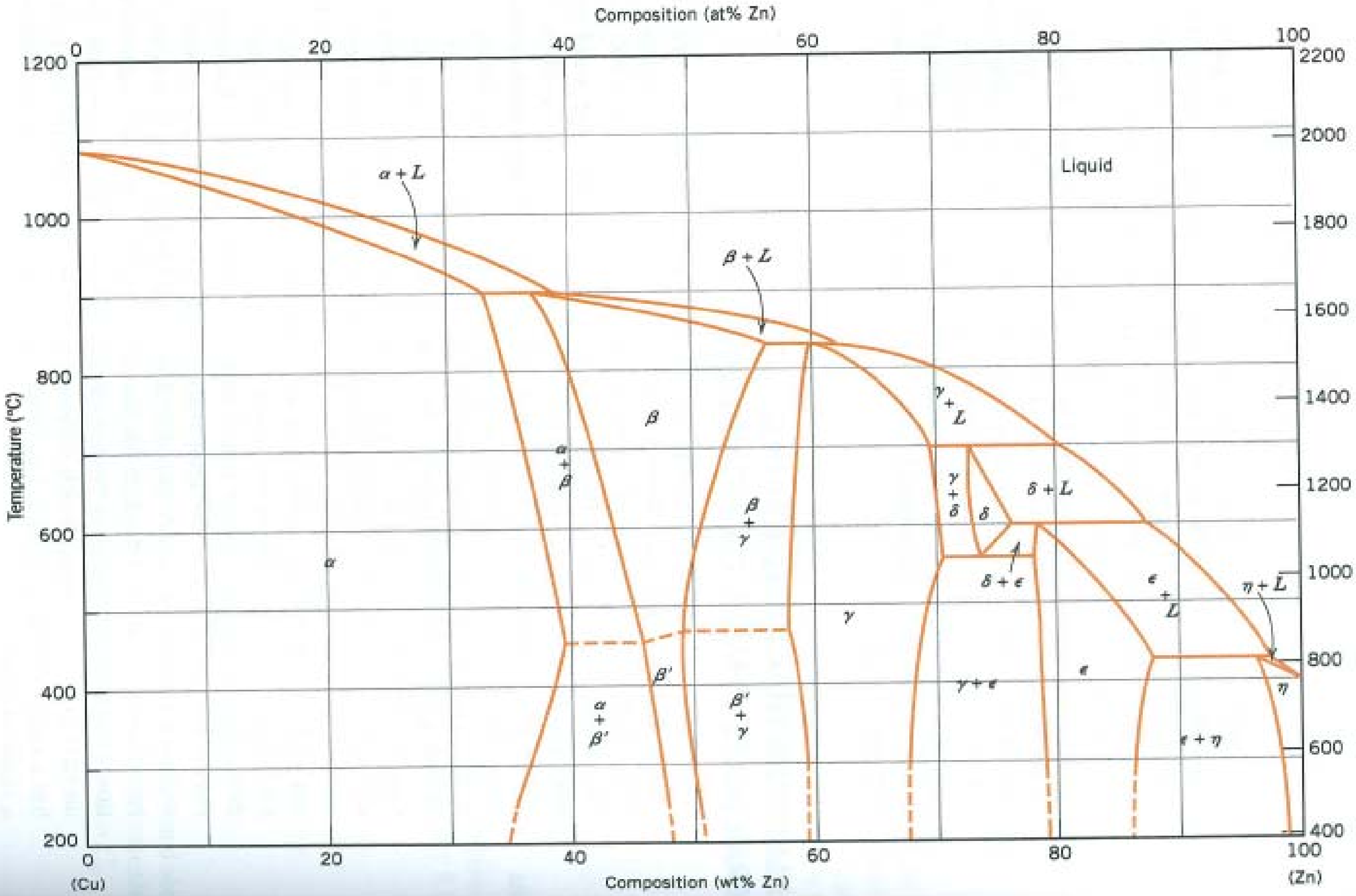
# 9. nonferrous metals

# Structural metallic materials

## 9.1 Copper and its alloys

**brass** : A copper-rich copper-zinc alloy



# Structural metallic materials

- Up to approximately 35%Zn----- α phase-----FCC
- α -brasses----soft, ductile, easily cold worked
- α and β ' phases at room temperature
- β ' phases----BCC----hard and stronger----fit for hot work

Application:

- Costume jewelry
- Cartridge casings
- Automotive radiators
- Musical instruments
- Electronic packaging
- coins

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# Structural metallic materials

## Copper and its alloys

**bronze** : A copper-rich copper-tin alloy;  aluminum, silicon, and nickel bronzes are also possible.

- Stronger than brasses
- Corrosion resistance

Beryllium copper

- Tensile strengths(1400MPa)
- Excellent electrical
- Corrosion property
- Wear  resistance
- Cast, hot worked, cold worked

# Structural metallic materials    Copper and its alloys

## Compositions, Mechanical Properties, and Typical Applications for Eight Copper Allots

| | | | | Mechanical Properties | | | |
|---|---|---|---|---|---|---|---|
| Alloys Name | UNS Number | Compositions(**(wt%)** | Condition[b] | Tensile Strength **(Mpa(ksi))** | **Yield Strength (Mpa(ksi))** | **Ductility(%EL in 50 mm (2in.)** | **Typical Applications** |
| | | | Wrought Alloys | | | | |
| Electrolytic tough pitch | C11000 | 0.04 O | Annealed | 220(32) | 69(10) | 45 | Electrical wire, rivets. Screening, gaskets, pans, nails, roofing |
| Beryllium copper | C17200 | 1.9 Be, 0.20 Co | Precipitation hardened | 1140-1310 (165-190) | 965-1205 (140-175) | 4-10 | Springs, bellows, firing pins, bushings, values, diaphragms |
| Cartridge brass | C26000 | 30 Zn | Annealed Cold-worked (H04 hard) | 300(44) 525(76) | 75(11) 435(63) | 68 8 | Automotive radiator cores, ammunition components, lamp fixtures, flashlight shells, kickplates |
| Phosphor bronze, 5％A | C51000 | 5 Sn, 0.2 P | Annealed Cold-worked (H04 hard) | 325(47) 560(81) | 130(19) 515(75) | 64 10 | Bellows, clutch disks, diaphragms, fuse clips, springs |
| Copper-nickel, 30％ | C71500 | 30 Ni | Annealed Cold-worked (H02 hard) | 380(55) 515(75) | 125(18) 485(70) | 36 15 | Condenser and heat-exchanger components, saltwater piping |
| | | | Cast Alloys | | | | |
| Leaded yellow brass | C85400 | 29Zn, 3Pb, 1 Sn | As cast | 234(34) | 83(12) | 35 | Furniture hardware, radiator fittings, light fixtures, battery clamps |
| Tin bronze | C90500 | 10 Sn, 2 Zn | As cast | 310(45) | 152(22) | 25 | Bearings, bushings, piston rings, steam fittings, gears |
| Aluminum bronze | C95400 | 4Fe, 11Al | As cast | 586(85) | 241(35) | 18 | Bearings, gears, worms, bushings, valve seats and guards, picking hooks |

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# Structural metallic materials

## 9.2 Aluminum and its alloys

- ✓Low density(2.7g/cm$^3$ as compared to 7.9g/cm$^3$ for steel )
- ✓High electrical
- ✓High conductivities
- ✓Resistance to corrosion
- ✓Excellent deformability (shaping)
- ✓Damage tolerant

- ×Low melting temperature (660℃)
- ×Moderate mechanical resistance
- ×Moderate stiffness

Application:

- ➢Aircraft structural parts
- ➢Beverage cans
- ➢Bus bodies
- ➢Automotive parts

# Structural metallic materials

## Aluminum and its alloys

### Compositions, Mechanical Properties, and Typical Applications for Several Common Aluminum Alloys

| | | | | Mechanical Properties | | | |
|---|---|---|---|---|---|---|---|
| Aluminum Association Number | UNS Number | Compositions((wt%)[a] | Condition(Temper Designation) | Tensile Strength(Mpa(ksi)) | **Yield Strength (Mpa(ksi))** | **Ductility(%EL in 50 mm (2in.)** | **Typical Applications** |
| | | | Wrought, Nonheat-Treatable Alloys | | | | |
| 1100 | A91100 | 0.12Cu | Annealed(O) | 90(13) | 35(5) | 35-45 | Food/chemical handling and storage equipment. Heat exchangers, light reflectors |
| 3003 | A930030 | 0.12Cu,1.2Mn,0.1Zn, | Annealed(O) | 110(16) | 40(6) | 30-40 | Cooking utensils and piping |
| 5052 | A95052 | 2.5Mg,0.25Cr | Strain hardened(H32) | 230(33) | 195(28) | 12-18 | Aircraft fuel and oil lines, fuel tanks, appliances, rivets, and wire |
| | | | Wrought, heat-Treatable Alloys | | | | |
| 2024 | A92024 | 4.4Cu,1.5Mg,0.6Mn | Heat-treated(T4) | 470(68) | 325(47) | 20 | Aircraft structures, rivets, truck wheels, screw machine products |
| 6061 | A96061 | 1.0Mg,0.60 Si,0.30Cu,0.20Cr | Heat-treated(T4) | 240(35) | 145(21) | 22-45 | Trucks, canoes, railroad cars. Furniture, pipelines |
| 7075 | A97075 | 5.6Zn,2.5Mg,1.6Cu,0.23Cr | Heat-treated(T6) | 570(83) | 505(73) | 11 | Aircraft structures, rivers, truck wheels, screw machine products |
| | | | Cast, heat-Treatable Alloys | | | | |
| 295.0 | A02950 | 4.5Cu,1.1Si | Heat-treated(T4) | 455(66) | 110(16) | 8.5 | Flywheel and rear-axle housings, bus and aircraft wheels, crankcases |
| 356.0 | A03560 | 7.0Si,0.3Mg | Heat-treated(T6) | 228(33) | 164(24) | 3.5 | Aircraft pump parts, automotive transmission cases, water-cooled cylinder blocks |
| | | | Aluminum-Lithium Alloys | | | | |
| 2090 | | 2.7Cu,0.25Mg,2.25Li, 0.12Zr | Heat-treated, cold worked(T83) | 455(66) | 455(66) | 5 | Aircraft structure-s and cryogenic tankage structure-s |
| 8090 | | 1.3Cu, 0.95 Mg, 2.0Li, 0.1Zr | Heat-treated, cold worked(T651) | 465(67) | 360(52) | | Aircraft structure-s that must be highly damage tolerant |

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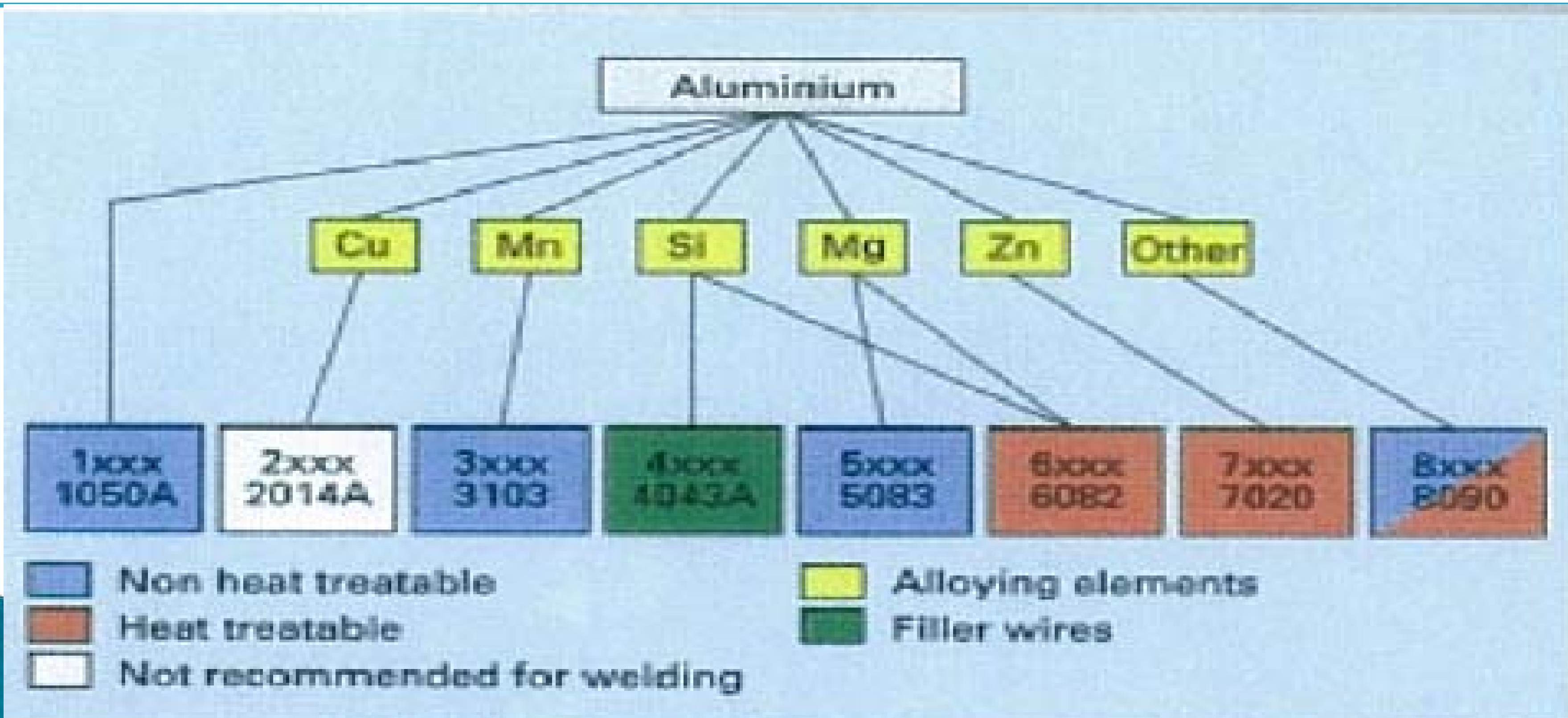
# Structural metallic materials

**Strain hardenable**: Mechanical properties enhanced by pre-deformation of the material

**Precipitation hardenable**: Mechanical properties enhanced by the precipitation of a finely distributed second phase



# Structural metallic materials

## 9.3 Magnesium and its alloys

✓Low density(1.7g/$cm^3$ , the lowest of all the structural metals )
✓HCP crystal structure---soft---low elastic modulus
✓Casting or hot working between 200 and 350℃
✓Excellent thermal conduction
× Low melting temperature (651℃)
× Susceptible to corrosion in marine environments
× Very low mechanical resistance
× Fine magnesium powder ignites easily when heated in air

Application:

- Aircraft
- Complex parts for missile application
- Luggage
- handheld device for automotive

# Structural metallic materials Magnesium and its alloys

## Compositions, Mechanical Properties, and Typical Applications for Six Common Magnesium Alloy

| | | | | Mechanical Properties | | | |
|---|---|---|---|---|---|---|---|
| ASLM Number | UNS Number | Compositions((wt%) | Condition | Tensile Strength**(Mpa(ksi))** | **Yield Strength(Mpa(ksi))** | **Ductility(%EL in 50 mm (2in.)** | **Typical Applications** |
| | | | Wrought Alloys | | | | |
| AZ31B | M11311 | 3.0 Al, 1.0 Zn 0.2 Mn | As extruded | 262(38) | 200(29) | 15 | Structures and tubing, cathodic protection |
| HK31A | M13310 | 3.0 Th ,0.6 Zr | Strain hardened, partially annealed | 255(37) | 200(29) | 9 | High strength to 315℃(600° F) |
| 2K60A | M16600 | 5.5Zn, 0.45zr | Artificially aged | 350(51) | 285(41) | 11 | Forgings of maximum strength for aircraft |
| | | | Cast Alloys | | | | |
| AZ91D | M11916 | 9.0 Al,0.45 Mn, 0.7 Zn | As cast | 230(33) | 150(22) | 3 | Die-cast parts for automobiles. Luggage, and electronic devices |
| AM60A | M10600 | 6.0Al, 0.13 | As cast | 220(32) | 130(19) | 6 | Automotive wheels |
| AS41A | M10410 | 4.3 Al, 1.0 Si, 0.35 Mn | As cast | 210(31) | 140(20) | 6 | Die castings requiring good creep resistance |

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# Structural metallic materials

## 9.4 Titanium and its alloys

✓Low density($4.5 g/cm^3$)
✓high melting temperature (1668℃)
✓Excellent corrosion resistance (protective $TiO_2$dense & compact)
✓Tensile strengths(1400MPa)
✓Highly ductile
✓Easily forged
✓Machined
× thermo-mechanically shape
× very bad friction property

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β－β

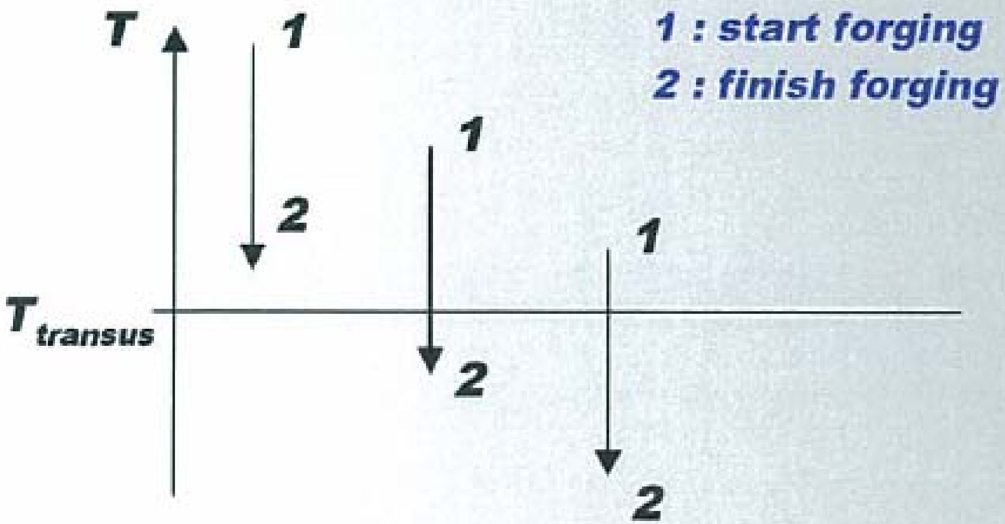
# Structural metallic materials Titanium and its alloys

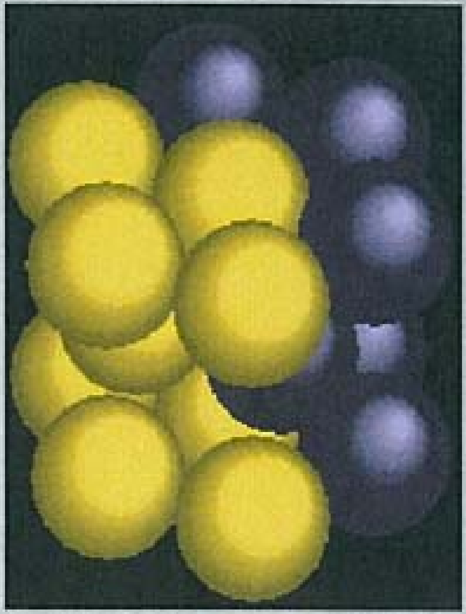
## Composition, Mechanical Properties, and Typical Applications for Several Common Titanium

| | | | | Average Mechanical Properties | | | |
|---|---|---|---|---|---|---|---|
| Alloy Type | Common Name (UNS Number) | Composition (wt%) | Condition | Tensile Strength (Mpa(ksi)) | Yield Strength(Mpa(ksi)) | Ductility(%EL in 50 mm (2in.) | Typical Applications |
| Commercially pure | Unalloyed(R50250) | 99.5Ti | Annealed | 240(35) | 170(25) | 24 | Jet engine shrouds , cases and airframe skins, corrosion-resistant equipment for marine and chemical processing industries |
| | Ti-5Al-2.5Sn(R54520) | 5 Al, 2.5 Sn, balance Ti | Annealed | 826(120) | 784(114) | 16 | Gas turbine engine casting and rings; chemical processing strength to temperatures of 480℃(900° F) |
| Near | Ti-8Al-1Mo-1V(R54810) | 8 Al,1 Mo, 1V, balance Ti | Annealed(duplex) | 950(138) | 890(129) | 15 | Forgoing for jet engine components (compressor disks, plates and hubs) |
| | Ti-6Al-4V(R56400) | 6 Al ,4V, balance Ti | Annealed | 947(137) | 877(127) | 14 | High-strength prosthetic implants, chemical-processing equipment, airframe structural components |
| | Ti-6Al-4V(R56620) | 6Al ,2 Sn, 6V, 0.75 Cu, balance | Annealed | 1050(153) | 985(143) | 14 | Rocket engine case airframe applications and high-strength airframe structures |
| | Ti-10V-2Fe-3Al | 10V,2Fe,3Al,balance Ti | Solution+ aging | 1223(178) | 1150(167) | 10 | Best combination of high strength and toughness of any commercial titanium alloys , used for applications requiring uniformity of tensile properties at surface and center locations; high-strength airframe components |

# Allotropic transformation of Ti & Ti alloys:

***Above $T_{transus}$ (882°C for pure Ti) : BCC ($\beta$ Ti)***
***Below $T_{transus}$ (882°C for pure Ti) : HC ($\alpha$ Ti)***



***Depending on the forging route : the microstructure may be fully $\alpha$, $\alpha+\beta$ or fully $\beta$***

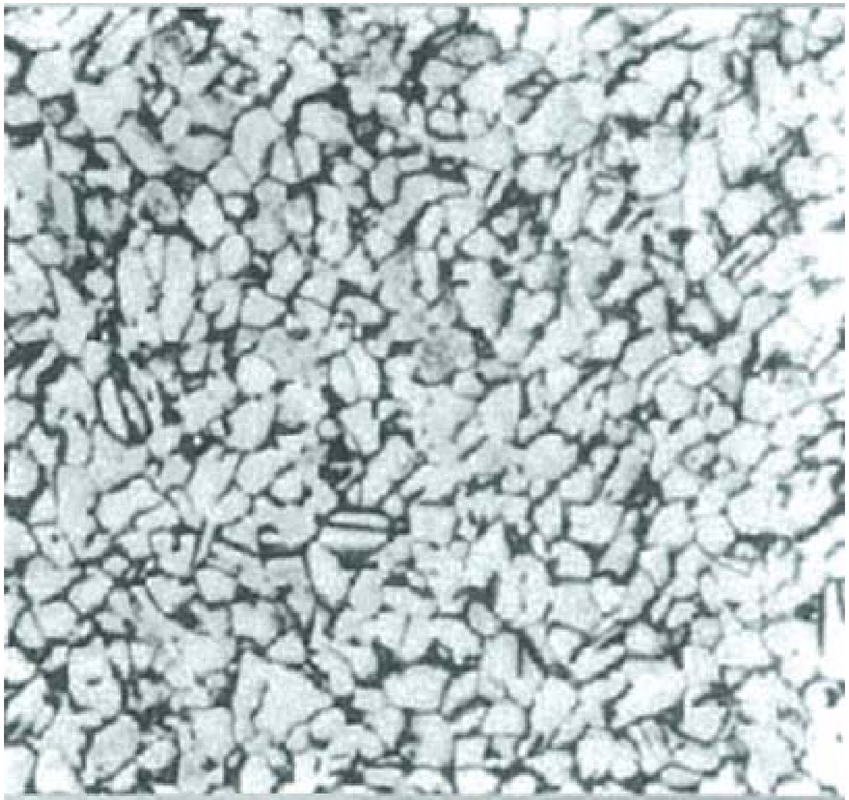
***The geometry of the part is the same`***

***But the microstructure and the properties are very different and definitive => Memory of Titanium***

# Ti tanium alloys: thermomechanical treatment

Deformation(thermomechanical) is required : loss of the shape

TA6V $\alpha$



TA6V $\alpha + \beta$

# Structural metallic materials

Application:

- Airplane structures
- Space vehicles
- Surgical implants
- Chemical industries

# Structural metallic materials

## Ti tanium alloys Application: landing gear

Forge libre

4500T

AIRBUS A380

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# Structural metallic materials

## Ti tanium alloys Application: landing gear

AIRBUS A380

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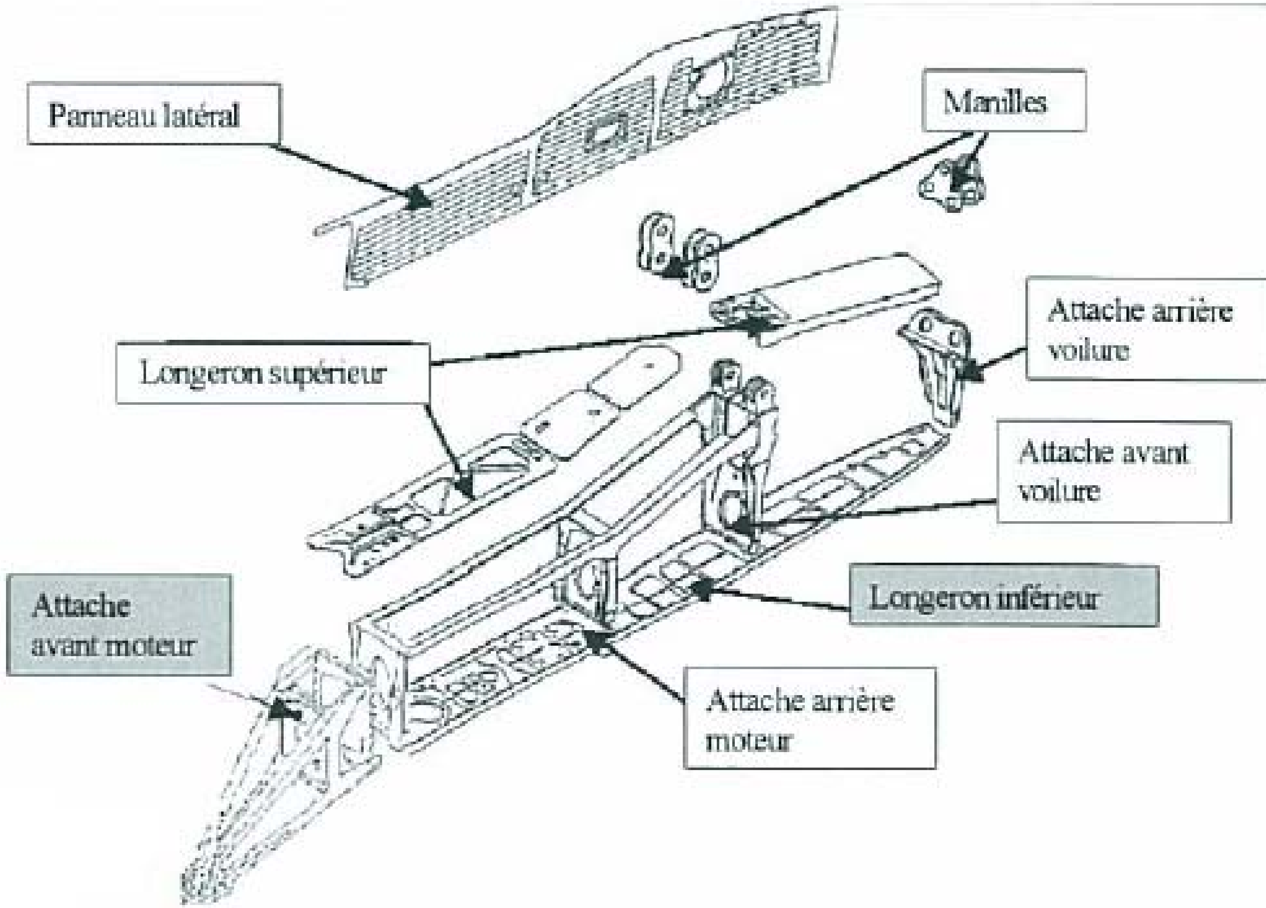
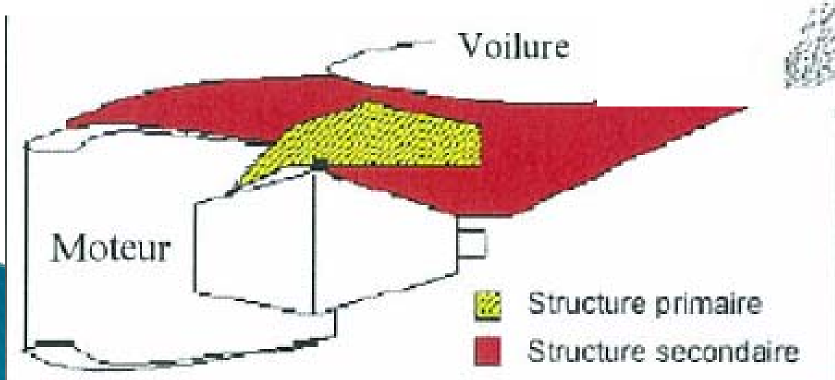
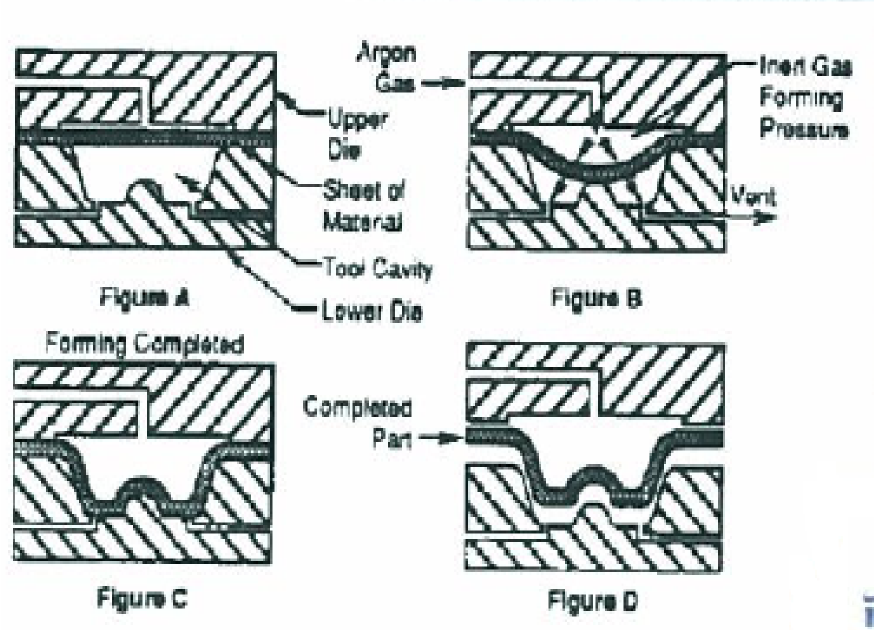
# Ti tanium alloys Application: engine pylon



# Ti tanium alloys Process principle




High temperature:900℃ for TA6V
Low strain rate
Very fine grain  microstructure

# Structural metallic materials

## 9.5 superalloys：

the super alloy have superlative combinations of properties.

Most are used in aircraft turbine components , which must withstand exposure to severely oxidizing environments and
High temperatures for reasonable time periods.

# Structural metallic materials

## The Superalloys

**Table 11.10 Compositions for Several Superalloys**

| Alloy Name | Composition (wt%) Ni | Fe | Co | Cr | Mo | W | Ti | Al | C | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *Iron–Nickel (Wrought)* | | | | |
| A-286 | 26 | 55.2 | — | 15 | 1.25 | — | 2.0 | 0.2 | 0.04 | 0.005 B, 0.3 V |
| Incoloy 925 | 44 | 29 | — | 20.5 | 2.8 | — | 2.1 | 0.2 | 0.01 | 1.8 Cu |
| | | | | | | *Nickel (Wrought)* | | | | |
| Inconel-718 | 52.5 | 18.5 | — | 19 | 3.0 | — | 0.9 | 0.5 | 0.08 | 5.1 Nb, 0.15 max Cu |
| Waspaloy | 57.0 | 2.0 max | 13.5 | 19.5 | 4.3 | — | 3.0 | 1.4 | 0.07 | 0.006 B, 0.09 Zr |
| | | | | | | *Nickel (Cast)* | | | | |
| Rene 80 | 60 | — | 9.5 | 14 | 4 | 4 | 5 | 3 | 0.17 | 0.015 B, 0.03 Zr |
| Mar-M-247 | 59 | 0.5 | 10 | 8.25 | 0.7 | 10 | 1 | 5.5 | 0.15 | 0.015 B, 3 Ta, 0.05 Zr, 1.5 Hf |
| | | | | | | *Cobalt (Wrought)* | | | | |
| Haynes 25 (L-605) | 10 | 1 | 54 | 20 | — | 15 | — | — | 0.1 | |
| | | | | | | *Cobalt (Cast)* | | | | |
| X-40 | 10 | 1.5 | 57.5 | 22 | — | 7.5 | — | — | 0.50 | 0.5 Mn, 0.5 Si |



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# Structural metallic materials


- ➢Distinguish
- ➢Security
- ➢Coinable
- ➢Wear resistant
- ➢Corrosion resistance
- ➢Value
- ➢Recyclability
- ➢Antibacterial

# Structural metallic materials

- 2-euro coin: this coin is termed bimetallic-it consists of an outer ring and an inner disk. For the outer ring, a 75Cu-25Ni alloy is used, which has a silver color. The inner disk is composed of a three-layer structure-high-purity nickel that is clad on both sides with a nickel brass alloy(75Cu-20Zn-5-Ni);this alloy has a gold color

- 1-euro coin: this coin is also bimetallic, but the alloys used for its outer ring and inner disk are reversed from those for the 2-euro coin

- 50-20-,and 10-euro-cent pieces: these coins are made of a "Nordic Gold" alloy-89Cu-5Al-5Zn-1Sn

- 5-2-,and 1-euro-cent pieces: copper-plated steels are used for these coins.

# Structural metallic materials

## 9.6 Aerospace Materials: selection criteria

# Structural metallic materials

## Aerospace Materials: selection criteria

**Material selection**

↓

**Tentative choice of material**

Consider metal, ceramic,

polymers, composites

**Component design**

↓

**Tentative component design**

Definition of operating conditions

# Structural metallic materials

## Aerospace Materials: selection criteria

**Assemble materials data**

Cost, Density

Elastic properties

Yield strength

Hardness

Tensile strength

Ductility

Fracture

Fatigue strength

Thermal conductivity

Specific heat

Thermal shock resistance

Creep parameters

Oxidation and corrosion rates

**Approximate stress analysis**

Mean stress

Bending moments

Buckling loads

Stress concentrations

Contact stresses

Permissible defections

Fatigue stresses

**Other constrains**

Environment

temperature

# Structural metallic materials

## Aerospace Materials: selection criteria

**Analysis of material performance in tentative design**

Reconsider choice of material or design as necessary, leading to material specifications for viable component design

↓

**Detailed specification and design**

Choice of material, detailed stress analysis. Detailed component design

↓

**Choice of production methods**

Forming, heat treatment, Joining, surface finish, Quality control detailed costing, Reconsider material choice and design as necessary

# Structural metallic materials

## Aerospace Materials: selection criteria

**Prototype testing**

Assessment of performance; analysis of failures, optimization of performance, and production

↓

**Establish production**

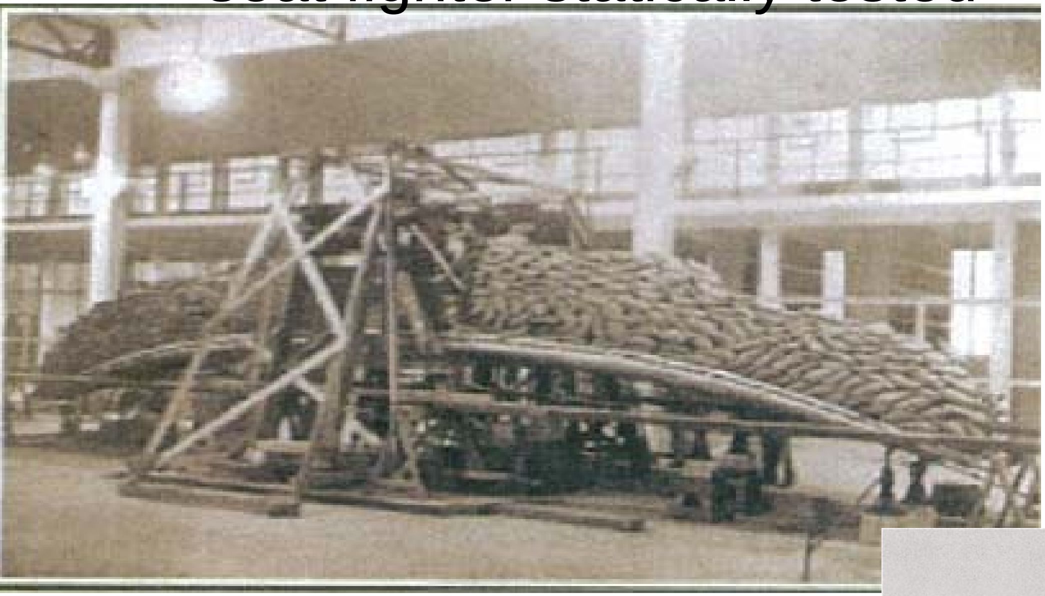
Monitor field failures, and performance and cost relative to competition

↓

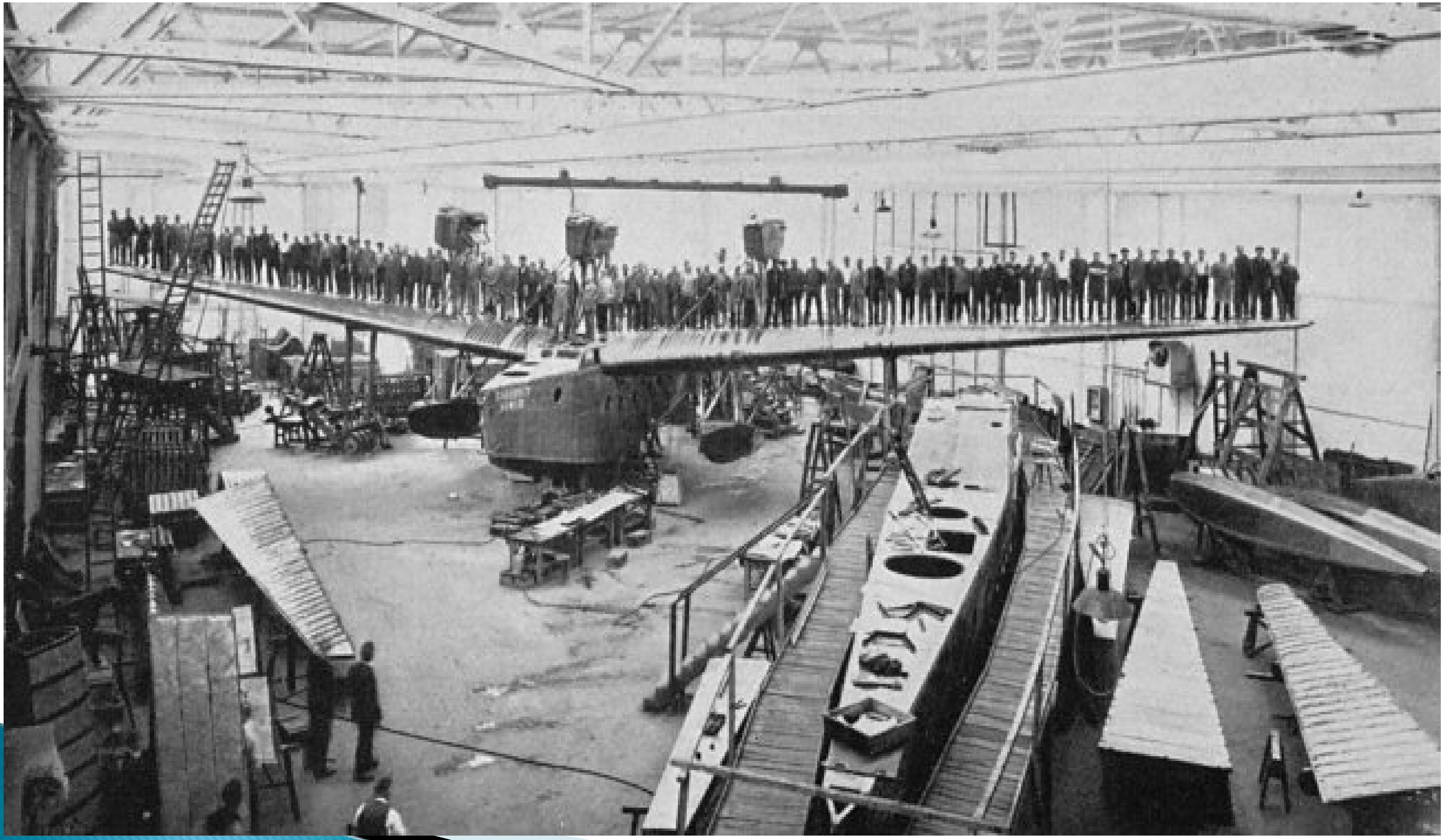
**Further development**

Improvements for better performance or lower costs. Innovation; new materials radically new design

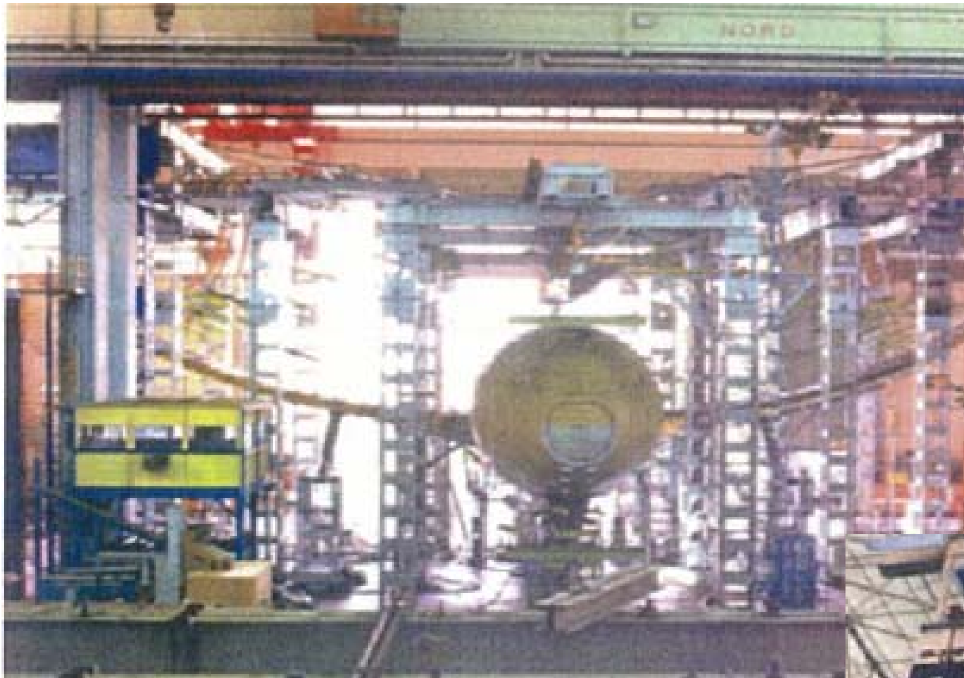
The upturned wing of a Dewoitime D-27 single seat fighter statically tested



One hundred men load the wing of a Rohrbach.Romar flying-boat which had an wing span approaching 40 metres(1928)



# Structural metallic materials



complex built to allow the loading of the wing

# Structural metallic materials

## Independent of time

**Physical :**

| | | | |
|---|---|---|---|
| Lightness | density | $\rho$ | $kg/m^3$ |
| Heat resistance | melting Temp. | $T_f$ | °C / K |
| Dimensional stability | thermal expansion | $\alpha$ | $°C^{-1}$ |
| Metallurgy | possibility to quench | | |
| | possibility to cast | | |
| | defect content | | |

# Structural metallic materials

## Independent of time

**Mechanical :**

| | | | |
|---|---|---|---|
| Mech. resistance | yield stress | YS ($R_{e\,0,2}$) | MPa |
| | ultimate tensile strength | UTS ($R_m$) | MPa |
| Ductility | elongation to fracture | A% | % |
| Stiffness | Young modulus | E | GPa |
| Resistance to shock | resilience (fracture energy per unit surface) | $K_{CU}$ | $J/cm^2$ |
| Resistance to Crack propagation | toughness | $K_{1C}$ | $MPa\sqrt{m}$ |

# Structural metallic materials

## Dependent of time

**Effect of time :**

| | | | |
|---|---|---|---|
| Fatigue | fatigue limit | $\sigma_D$ | MPa |
| | fatigue life | $N_R$ | cycles |
| | notch sensitivity | $q$ | |
| Damage tolerance | crack propagation rate | da/dN | m/cycles |

**Effect of time & temperature :**

| | |
|---|---|
| Creep | creep rate |
| Ageing | microstuctural evolution |
| | oxidation rate |

# Structural metallic materials

## Manufacturing criteria

**Manufacturing process :**

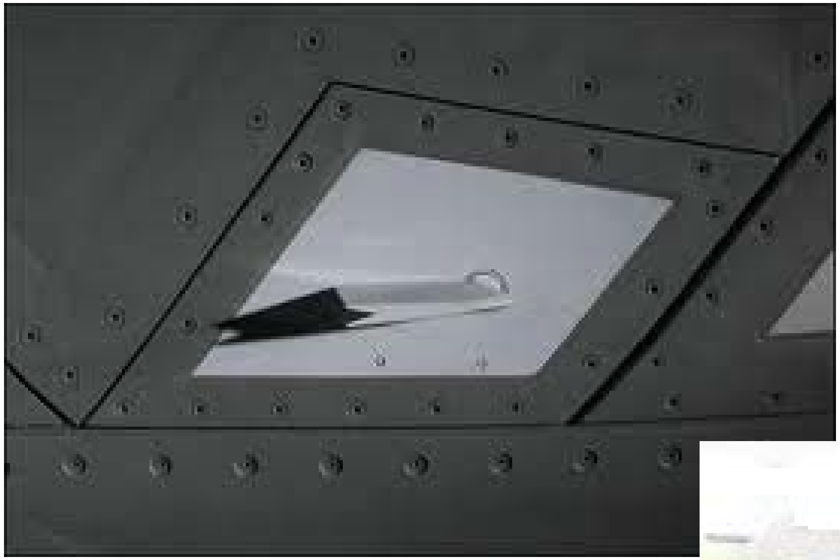
| | |
|---|---|
| With material removing | machining |
| Without material removing | casting or powder metallurgy<br>forming (forging, rolling, deep drawing, superplastic forming....) |

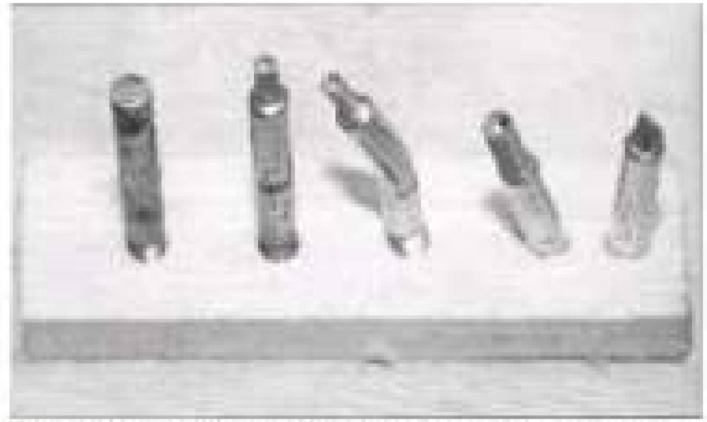
**Assembling process :**

Welding (TIG, MIG, FSW...), Soldering, Diffusion Bonding, Riveting (2 millions rivets on A340), Sticking....

# Structural metallic materials

## Manufacturing criteria





# Structural metallic materials

**Processing :five candidates**

- **Machining**
- **Sintering/HP**
- **Casting**
- **Welding**
- **Forging**

# Structural metallic materials

## Candidate materials for frame applications

**Metallic alloys**

- ✓ aluminum alloys
  (50 % of the frame)
- ✓ magnesium alloys
  (0 % of the frame
  mostly for missiles)
- ✓ titanium alloy
  (few percents)
- ✓ steels
  (few percents)

**Composite materials**

- ✓ polymer matrix composites
  matrix : polymer
  fibres : metal, glass, carbon,
- ✓ metal matrix composites
  matrix : aluminum
  fibres : glass, carbon, kevlar
- ✓ ceramic matrix composites
  matrix : C, SiC
  fibres : C, SiC

**Frame (mass %) : Al 50%, Composite 20%, Steel 13% Ti 6%, others balance**

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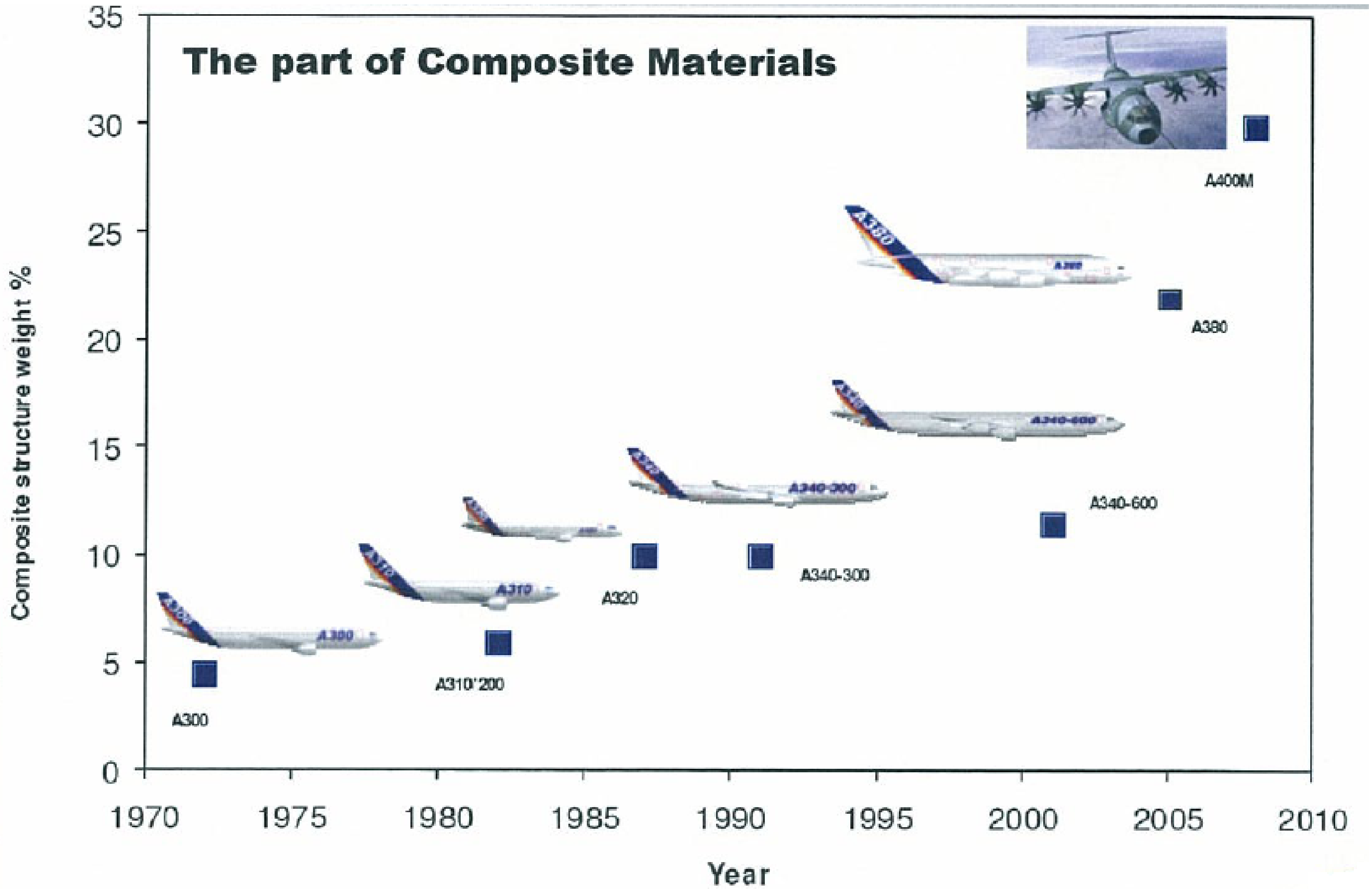
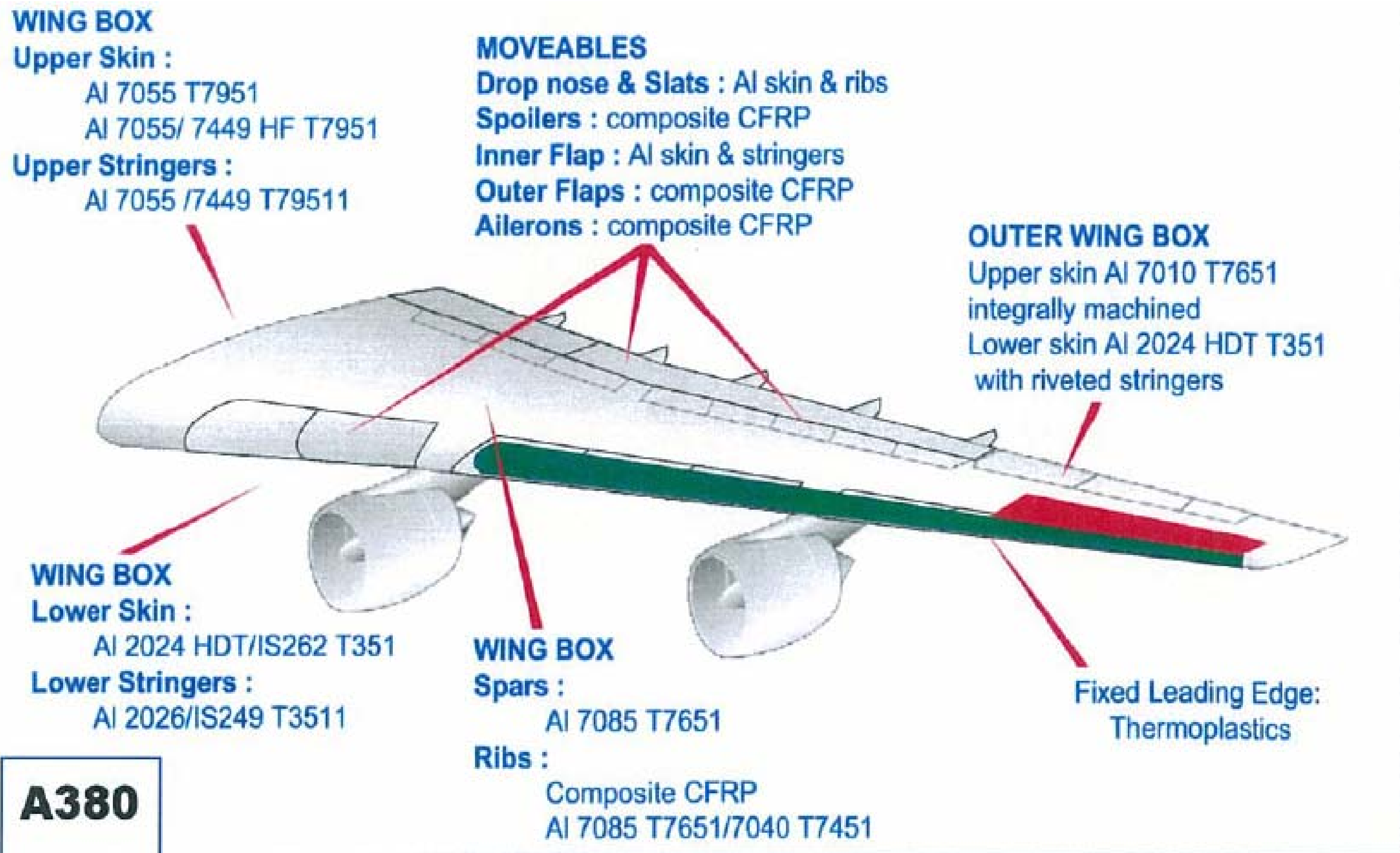
# Structural metallic materials

## Candidate materials for frame applications



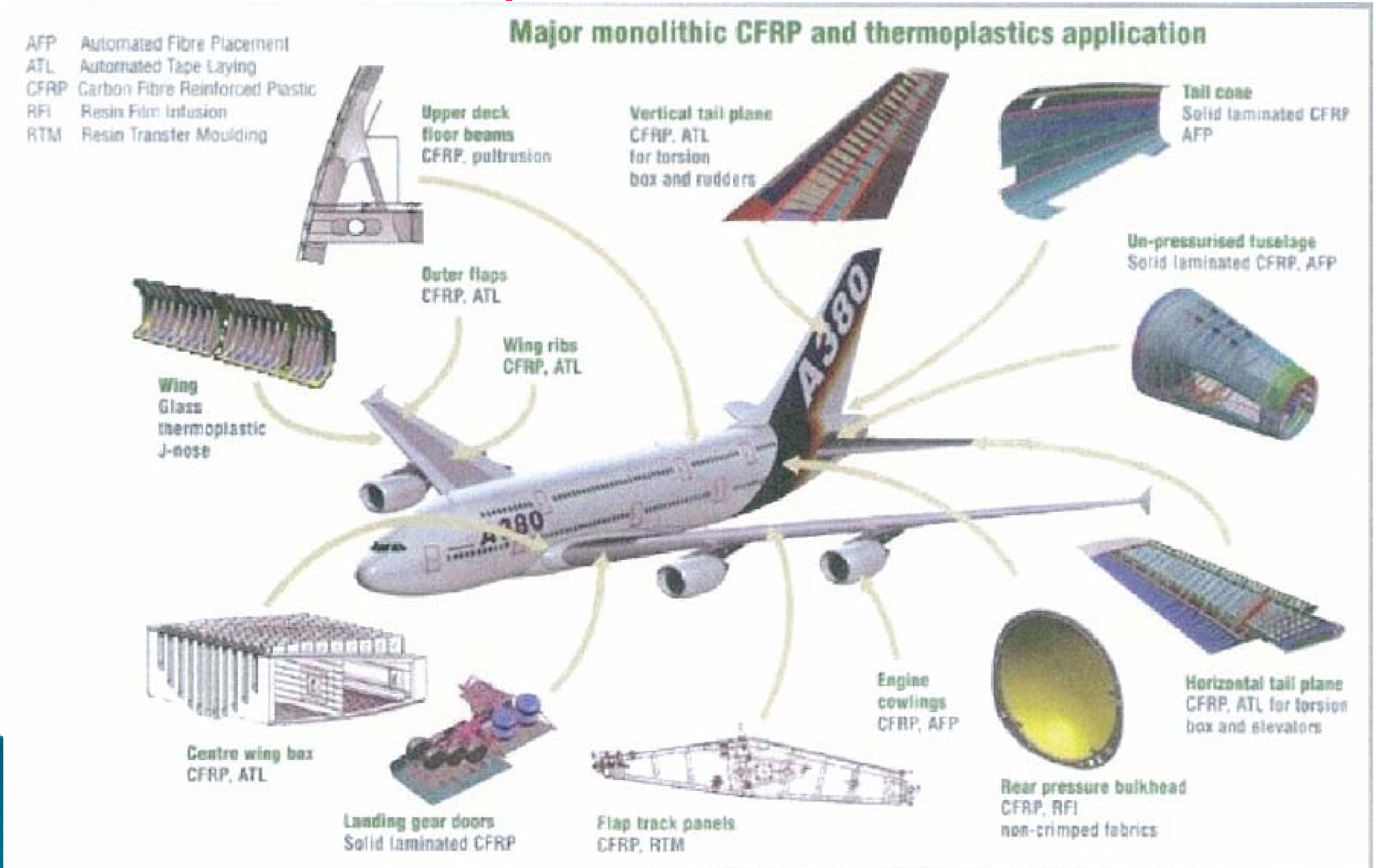
# Structural metallic materials

## Introduction to Aerospace Materials



# Structural metallic materials

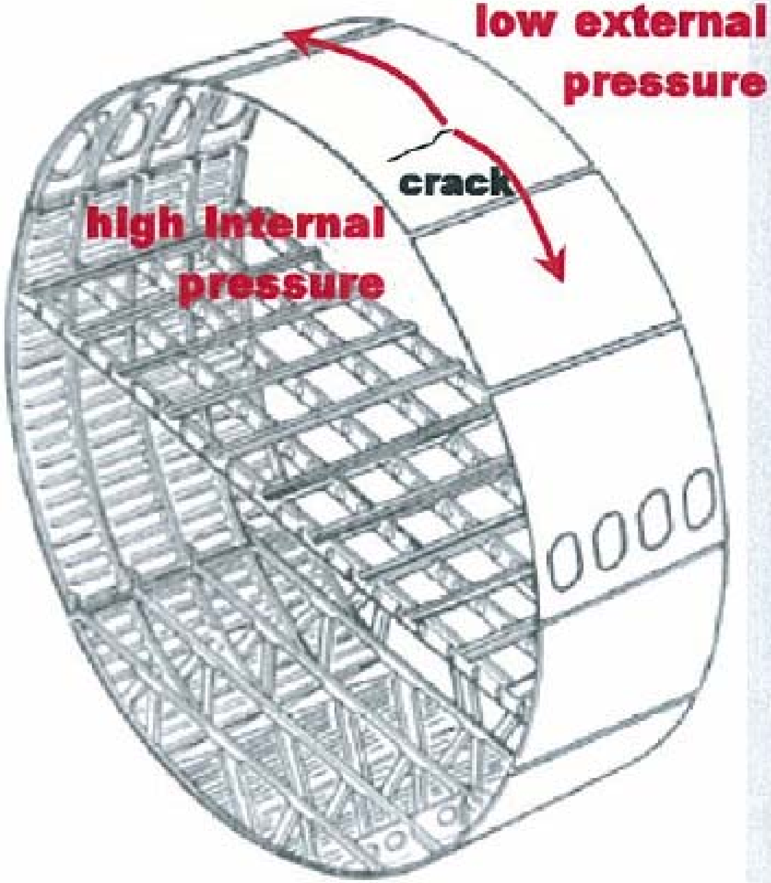
## Introduction to Aerospace Materials



# Structural metallic materials

## Candidate materials for frame applications

Next technological jump : 100% composite fuselage ?




✔ today limitation

- because the cockpit is pressurized
  crack propagation & air-tightness
- because still difficult to manufacture large parts
  "hand craft" small scale composite fabrication



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# Structural metallic materials

## Candidate materials for frame applications

### Composites - Introduction

- ✔ **anisotropic materials**

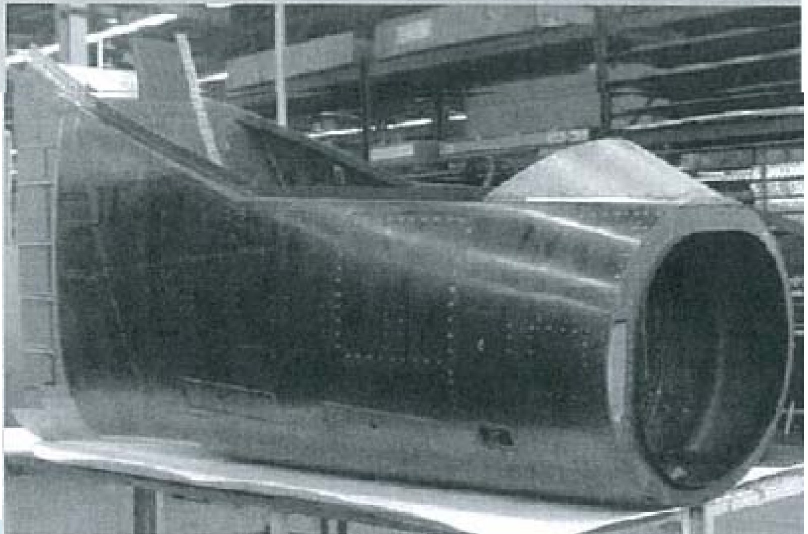
  two or more materials, chemically and geométrically different, combined on a macroscopic scale to form a useful material

- ✔ **light materials**

  on A320, the use of C/Epoxy allows a weight gain of 1650 kg (2.8% of the airplane total mass)

  => save 3300 tons of kerosene over the airplane life = 1.7

- ✔ **require to re-think in term of design**



# Structural metallic materials

## Candidate materials for frame applications

### Composites - Introduction

✔ **benefits**

- controlled anisotropy of mechanical properties
- no fatigue
- complex shape achievable / number of parts lowered
- repairable



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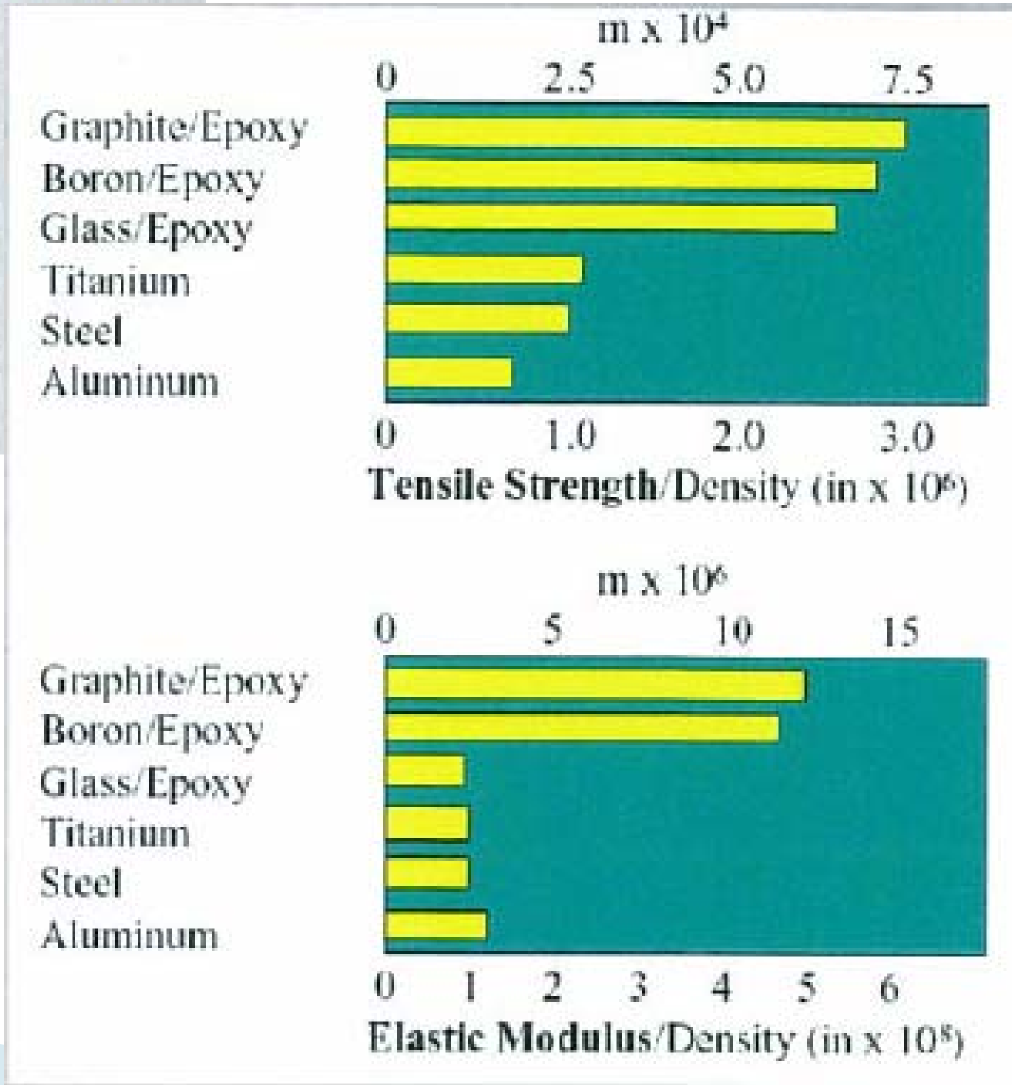
# Structural metallic materials

=> Ideal for structures where high strength-to-weight and high stiffness-to-weight ratios are required

=> Limited to in-plane distributed load (bi-dimensional parts)

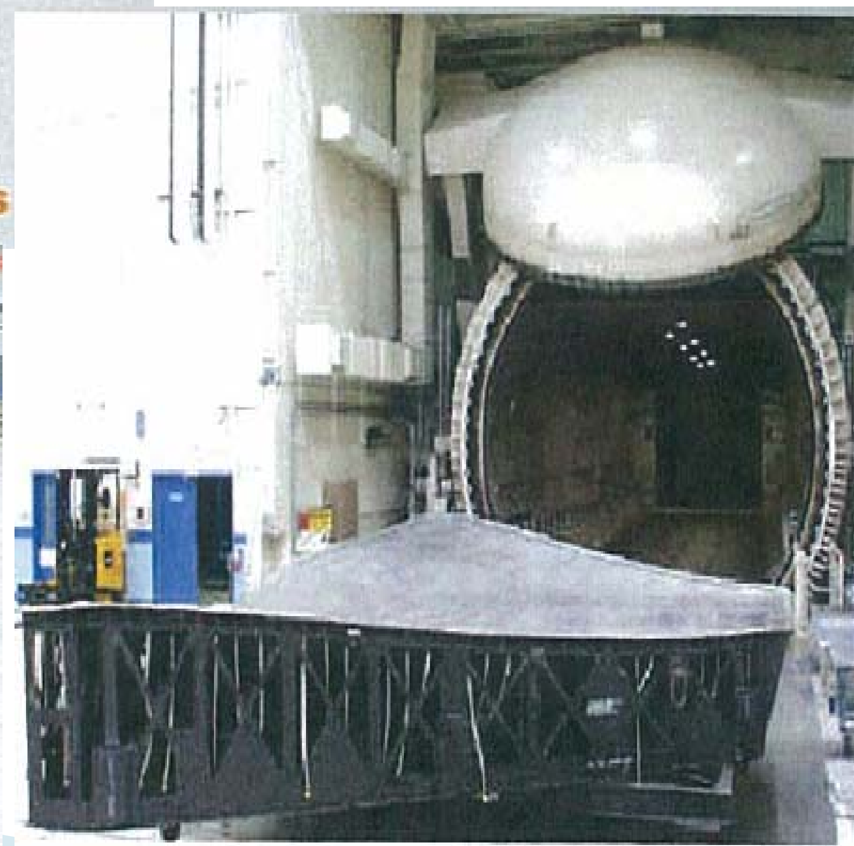


# Structural metallic materials

## Composites - Introduction

✔ drawbacks

- high notch sensitivity (crack propagation)
- low resistance to shocks
- low resistance to lightning
- low resistance to fire
  / toxicity of smokes
- difficult to assemble with metals
- difficult to automate the mfg process



# Structural metallic materials

## Composites - Fibres

- ✔ glass (10 - 20 μm)
- ✔ aramide (Kevlar®)
- ✔ polyethylene
- ✔ boron (100 μm)
- ✔ SiC (silicon carbide) (15 μm)
- ✔ Carbon (7 μm)

- stiffness +

Fibres are inserted

- in a polymer matrix

  polymer matrix composites

- after sizing (chemical coating)

  to lower the friction on mfg tools

  to enhance the chemical bonding to the matrix