Materials for aircraft engines

Aircraft Propulsion ASEN 5063

December 17, 2015

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Background – Engine Design

- To improve engine performance, mainly Specific Fuel Consumption (SFC)
  - Increase Bypass ratio
  - Increase pressure ratio
  - Weight Reduction
  - Increase Turbine Entry Temperature (TET)

- Safety Requirement

Mechanical property test and Engine Test

Material distribution in a modern engine

▪**Ni-based Superalloys**
- ~50% of the total weight
- Used in hot sections

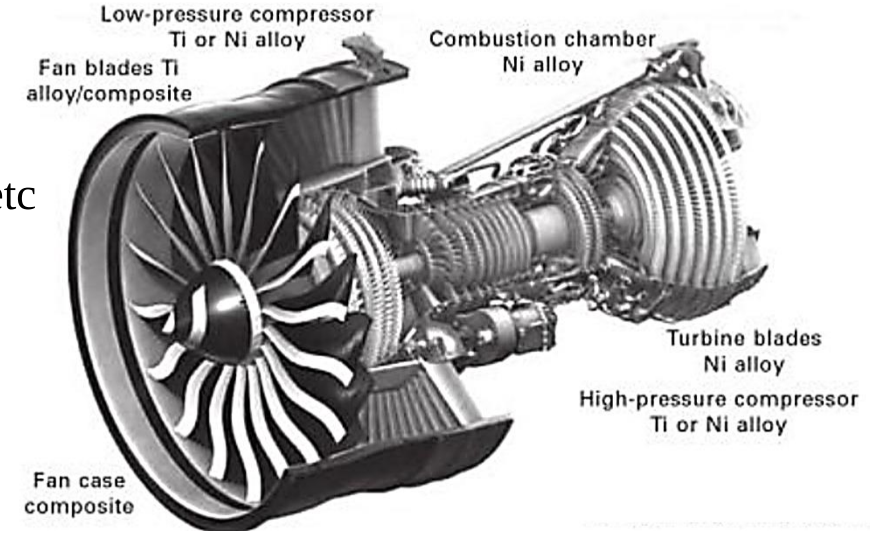
Turbine blades, discs, vanes, combustion chamber, etc
- High density of 8 ~ 9 g/cm^3

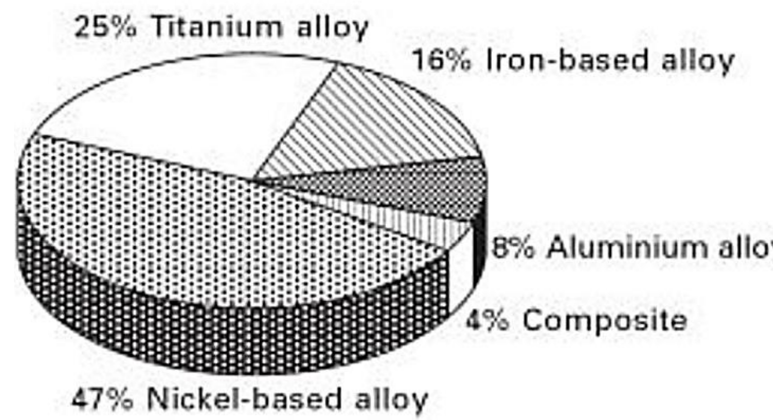
▪**Titanium alloys**
- Used in relatively cold sections

Fan, Compressor, etc
- Low density of 3.5 ~ 4.5 g/cm^3
- Ti-6Al-4V alloys

Form TiAl + Ti_3Al phases

▪**Composites**
- Used in Fan case and blades
- Even lighter than Titanium alloys
- Low high-temperature oxidation resistance
- Carbon Fiber Reinforced Plastic composite (CFRP)

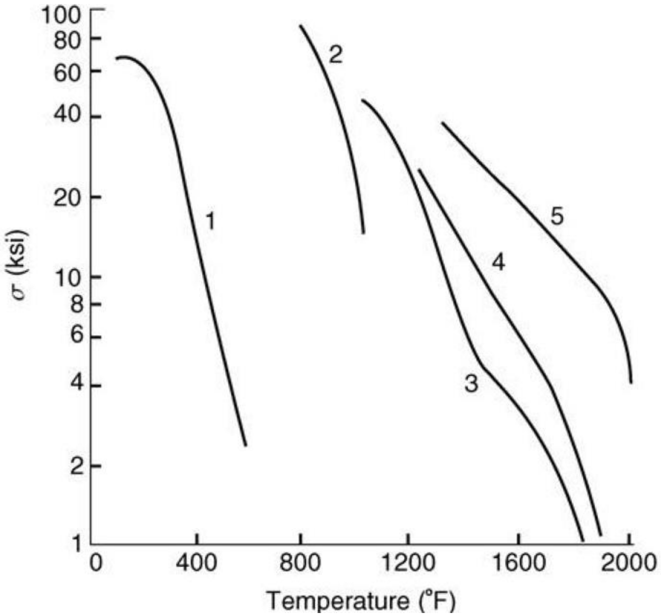




Material Distribution in CF6 (GE engine)

Titanium alloys

▪ **Reasons**
- Titanium alloys show higher specific strength than Nickel alloys below 800 ~ 900 K
- Weight saving
- Heat resistance
- Resistance to embrittlement at low temperature
- High corrosion resistance
- Low thermal expansion



Material	No.
Aluminum alloy	1
Titanium alloy	2
Wrought nickel alloy	3
High-strength nickel alloy	4
Single-crystal superalloy	5

▪ **Application**
- Frame and joint
- Fan blade and disc

Ti-6Al-4V alloys
- Low-pressure compressor blade

Ti-6Al-4V alloys
- High-pressure compressor blade

Ti-8Al-1Mo-1V alloys, Ti-6Al-2Sn-4Zr-6Mo alloys, etc
- Compressor disc

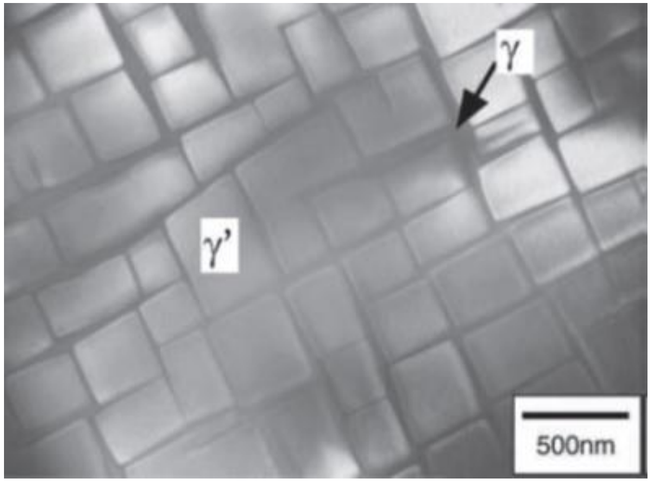
Ti-6Al-2Sn-4Zr-2Mo-0.1Si alloys, Ti-6Al-2Sn-4Zr-6Mo alloys

Turbine Blade

Co-based superalloys

↓

Ni-based superalloys



Microstructure of Ni-based superalloys

▪Why Ni-based superalloys?

- Ni is much cheaper than Co
- high strength
- long fatigue life
- oxidation and corrosion resistance at high temperature

γ : Ni matrix

γ' : Ni_3Al precipitation strengthening phase

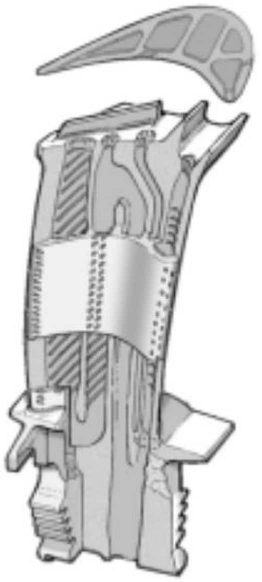
▪Microstructure of Ni-based superalloys

Ni and Ni3Al phases (both FCC structure)

→ Close lattice parameters between two phases

→ Wide composition range

Additives and Cooling systems



Ti, Ta: Solid solution strengthening of Ni_3Al

Cr: Solid solution strengthening and corrosion resistance

C: combines with Cr, gives precipitates in Ni

Co: Improves oxidation and corrosion resistance and stability

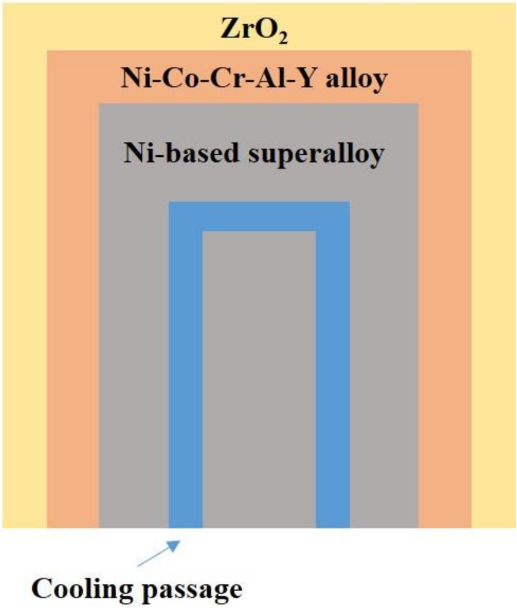
Mo, W: solid solution strengthening of Ni

Ti, Ta: solid solution strengthening of Ni_3Al

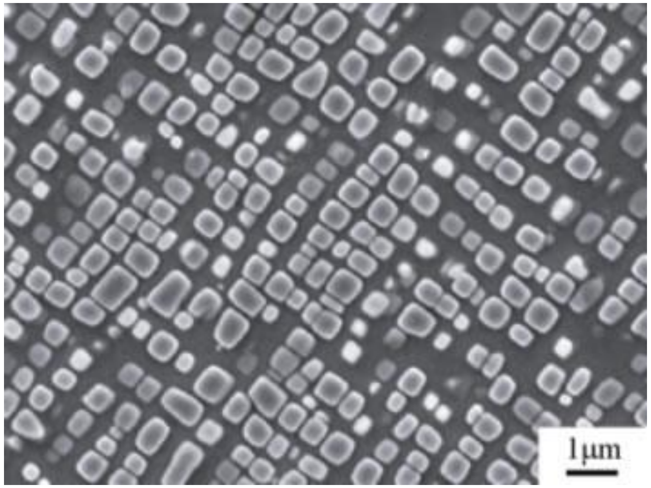
B: Improves grain boundary and suppresses cavity formation in creep

Hf: Improves ductility

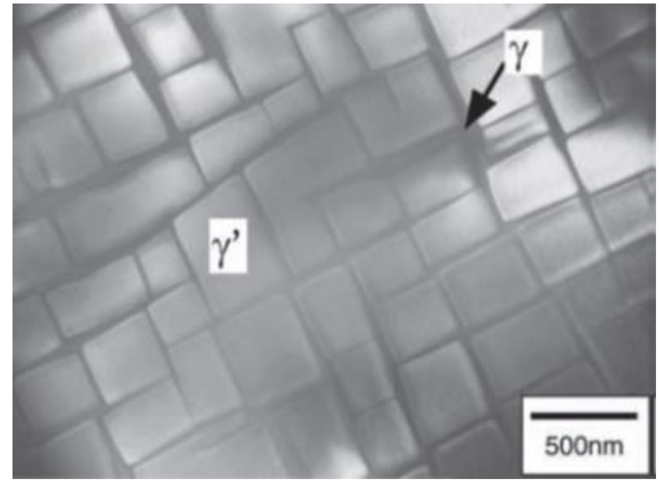
Y: Improves oxidation resistance



Promising superalloys



Co-Al-W alloys



Ni-Al alloys

▪**Co-Al-W alloys**
→ has the same structure with Ni-Al alloys
→ $Co_3(Al,W)$ phase can be stable over 1200K by adding Ta, Ti, etc.
→ higher strength and higher melting point by 50~100 degC

▪**Ir-Al-W alloys**
→ has the same structure with Ni-Al alloys
→ At 1000 degC, has twice Ni-Al alloys strength
→ Ir has high melting point (2447 degC)

Science Magazine (2006)
Science 7, Vol.312, No.5770, pp.90-91

Conclusion

- Improving the SFC is an essential task.

- Titanium alloys and Composite trend and demand have increased in recent years.

- Ni-based superalloys are main turbine blade materials and have been improved.

- To increase TET, improving turbine blade materials is required for future aircraft engines.

- There are infinite options for material selection.

Questions ?

Supplement

How to fabricate Ni-based superalloys

Casting Techniques to form single crystal

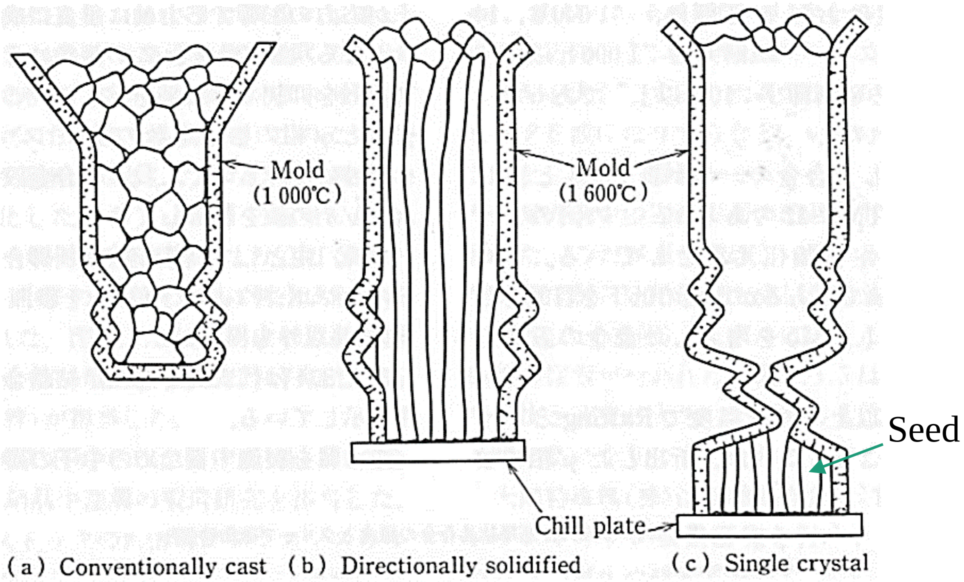
・Optical Floating Zone (OFZ) melting method

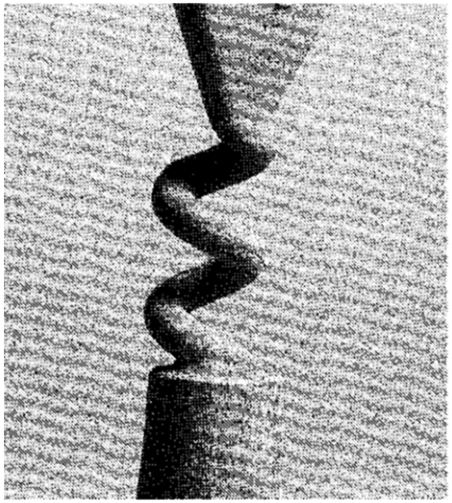
→ Cannot form big materials

→ Used usually for research to make samples

・Bridgeman method

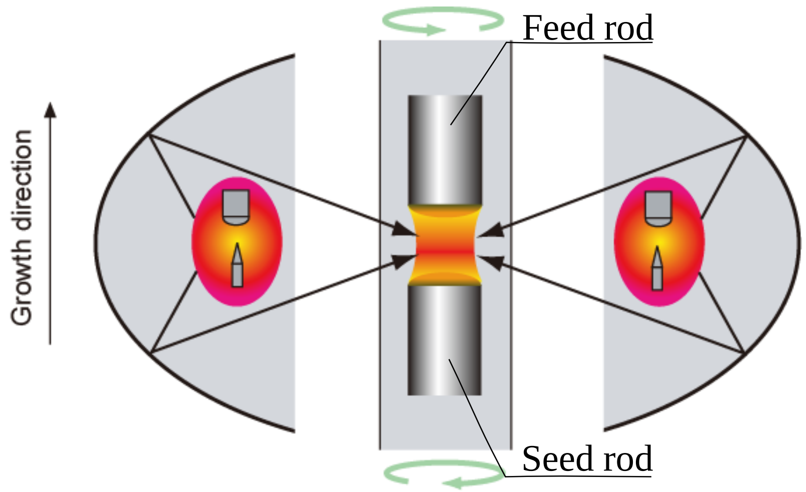
Slowly cooling a melted material so that the material can grow the single crystal only by using a seed material.

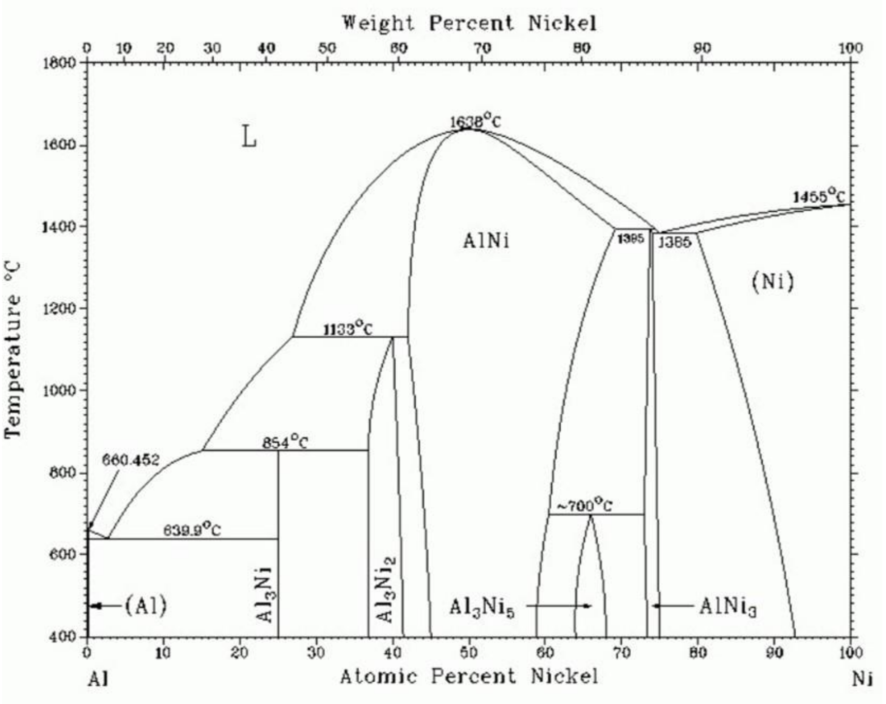


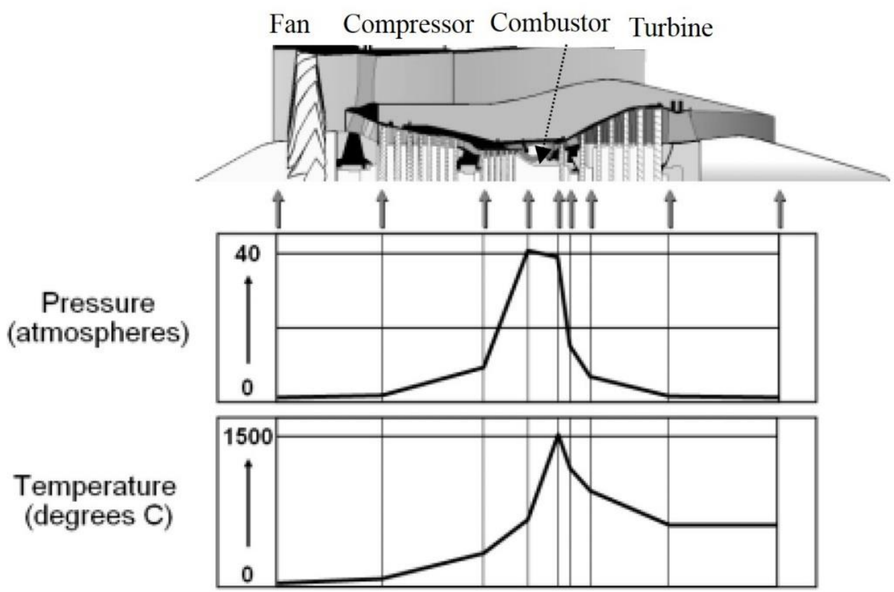


Grain Selector for Trent 800

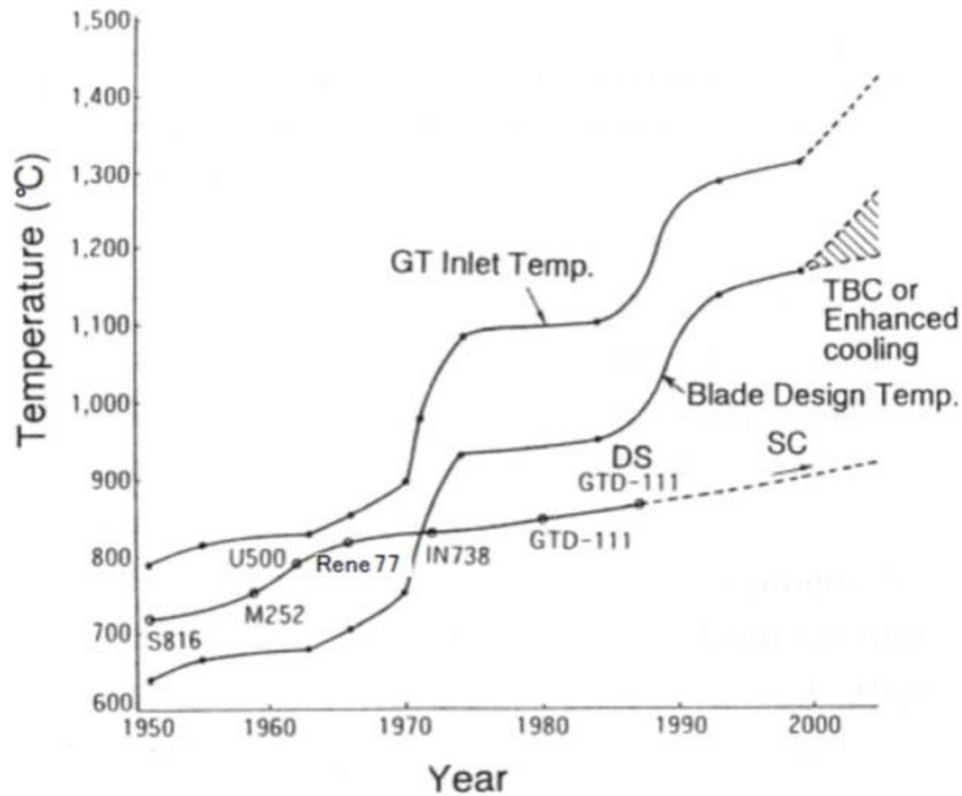
Optical Floating Zone melting : OFZ







Fan
Compressor
Combustor
Turbine
Pressure (atmospheres)
40
0
Temperature (degrees C)
1500
0



Temperature (°C)
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
1950
1960
1970
1980
1990
2000
Year
GT Inlet Temp.
Blade Design Temp.
TBC or Enhanced cooling
DS
SC
GTD-111
GTD-111
IN738
Rene 77
U500
M252
S816