NICKEL BASED SUPERALLOYS IN GAS TURBINE ENGINES

By Lee Sheets
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Turbine engines are used in a variety of energy technologies including:

- Nuclear (steam engine)
- Land generators for grid augmentation
- Marine (boat engines)

Efficiency enhancement:

- Increased operation temperatures
- Lighter material (aviation applications)
The hot section of the engine is the region where Ni-base superalloys are used.

- High pressure turbine
Many elements are used to create desired phases within the material.

Commonly:
- Precipitation strengthening (Ti, Al)
- Corrosion and Oxidation Resistance (Cr, Al)
- Grain boundary strengthening (B, carbides)
- Rhenium has become important in turbine blades, but has many issues
Typical Phases

- Gamma Matrix (γ)
  - FCC Ni solid solution
- Gamma Prime (γ’)
  - FCC Ni$_3$(Al,Ti)
  - Coherent particle strengthening
  - Microstructure after initial HT and after simulated aging
PHASES

- **Additional phases**
  - **Gamma double prime (γ”)**
    - Ni$_3$V or Ni$_3$Nb
    - Strengthener at low T, issues at high T
  - **Sigma (σ)**
    - Topologically close packed (TCP) phase
    - Embrittles material
    - Decrease lifetime by 50%
PROCESSING

- Polycrystalline Disk Alloy
  - Disks face much lower temperatures than the blades, but face larger stresses depending on region
  - Fatigue resistance is key, creep is also important

Powder metallurgy used
- Expensive
- Time consuming
- Energy and cost intensive
**Single-Crystal Blade Alloy**

- Blades made in a variety of ways, but this has the best balance of properties, creep resistance
  - Longest engine life ~
- Slow process, creating few blades per heat
- Cast and columnar blades cannot perform at as high temperatures, are used outside of aviation applications
THERMAL BARRIER COATING

- TBC - Ceramic coating deposited onto bond coat
  - Yitria stabilized zirconia used as TBC
  - Bond coats are typically an intermetallic compound, often platinum aluminide
    - Required due to inability of ceramic to bond with metal

Two main processes

- Air-plasma-sprayed (APS)
- Electron-beam physical-vapor-deposition (EB-PVD)
THERMAL BARRIER COATING

- **APS**
  - Used for land based applications
  - Liquid zirconia sputtered onto base layer, forming polycrystalline pancakes.
    - These sinter together during operation temperatures increasing the thermal conductivity
EB-PVD

- More reliable technology, aviation applications
- Vacuum chamber, tungsten filament is used to shoot electrons to heat plasma into gas which deposits onto surface of bond coat.
- Columnar ceramic structure created
  - More able to withstand debris impact during operation
CONCLUSIONS

- Ni-base superalloys have many benefits to conventional alloys but still have a long way to go to increase engine efficiency
  - Withstanding higher temperatures for longer periods of time
  - Increased fatigue and creep resistance
  - Thermal barrier coatings need further work in processing and mechanical properties
  - Reduce processing and element energy costs