Turbine Blades and Single Crystal

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Turbine blades introduction

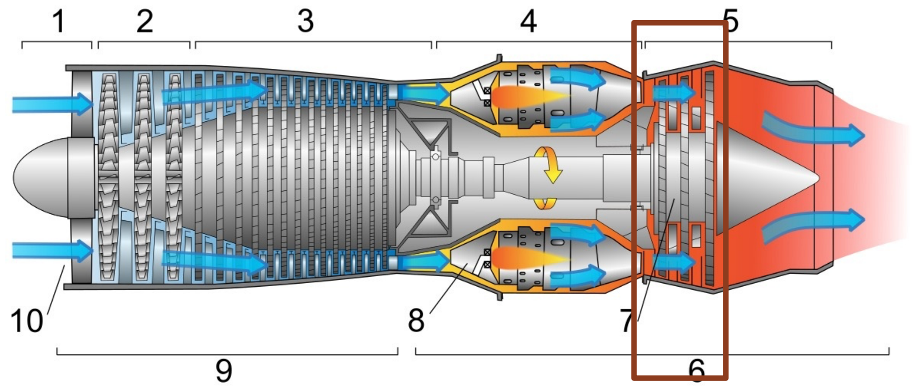
Issues and solutions

Creep

- Tendency of blade materials to deform at a temperature dependent rate under stresses well below the materials' yield strength

Solution

- Cooling
- Improved material



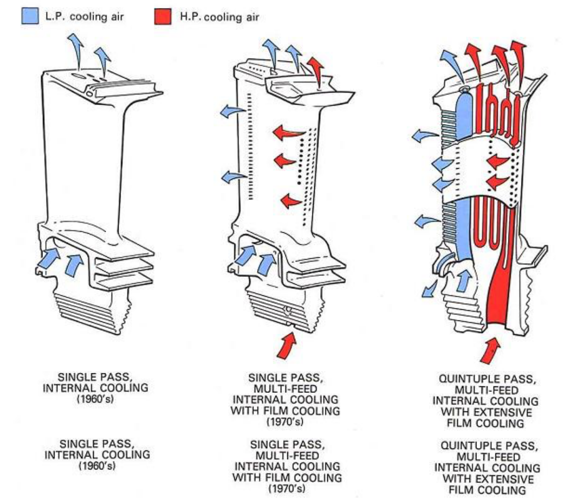
Cooling of turbine blades

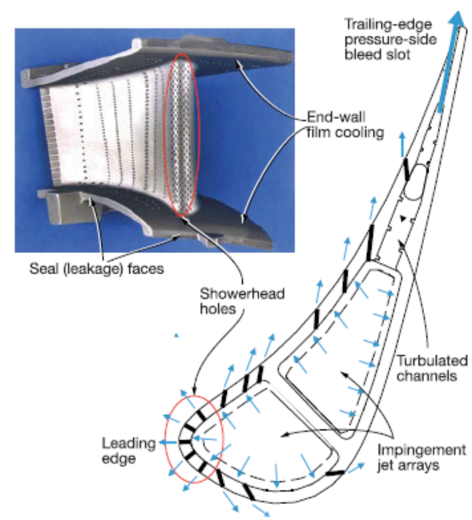
Internal cooling

- Convective cooling
  - passing cooling air through passages internal to the blade
  - heat is transferred by convection into the air flowing inside of the blade
- Impingement cooling
  - hitting the inner surface of the blade with high velocity air
  - used in the regions of greatest heat loads

External cooling

- Film & transpiration cooling
  - creates a thin film of cooling air on the blade by injecting/leaking air through small holes in the structure
- Effusion cooling
  - cooling air forced through porous holes which forms a film or cooler boundary layer on blade surface
- Pin fin cooling





4. HP-turbine nozzle is mainly cooled using internal impingement jet arrays, an abundance of discrete rows of film holes, and axial cooling channels within the thin trailing edge. It uses between 7% and 13% of compressor discharge air for cooling and leakages of airfoils and end walls, depending on combustor exit temperature, airfoil count, and loading

Material of turbine blades

Superalloys

- Advantages
  - excellent mechanical strength
  - resistance to thermal creep deformation
  - good surface stability
  - resistance to corrosion or oxidation
- Chemical composition
  - Base: Nickel (Ni)
  - Additional elements: Cobalt (Co), Tantalum (Ta), Aluminum (Al), Tungsten (W), rhenium (Re), others
- Fabrication
  - Vacuum induction melting (1950s)
  - Hot isostatic pressing

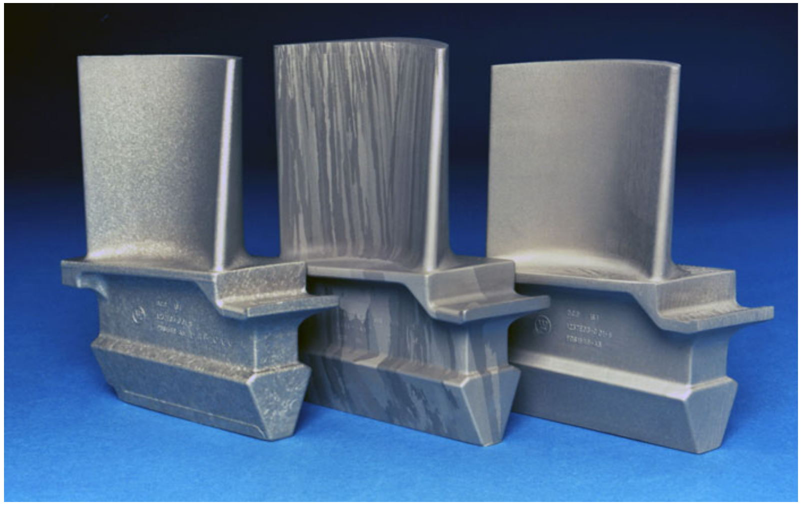
Thermal barrier coatings (TBC)

- Material: aluminide (1970s), ceramic (1980s)
- Improves corrosion and oxidation resistance

Directional solidification and single crystal

Single crystal turbine blades

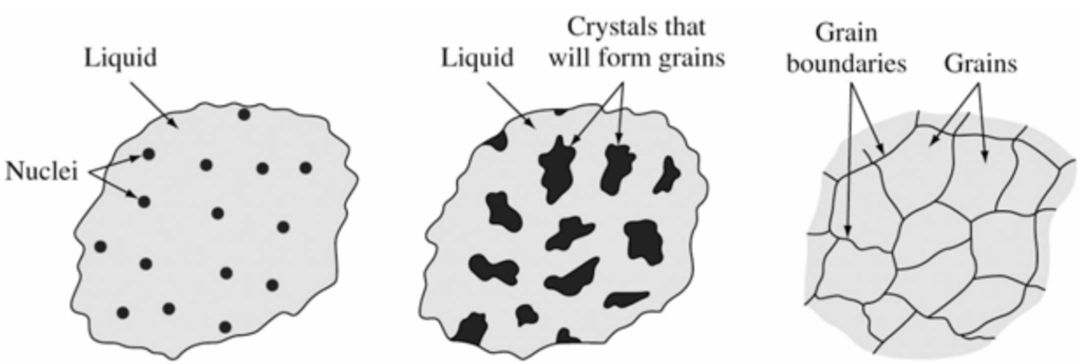
- A **single crystal** is a material in which the crystal lattice of the entire sample is continuous and unbroken to the edges of the sample (no grain boundaries)
- Properties
  - **Anisotropic** (depending on crystallographic structure)
  - **Improved ductility and thermal fatigue life** (failure of material, e.g. crack/fatigue initiation, corrosion, starts from imperfections or impurities in crystalline structure)
  - **More tolerance to localized strains**

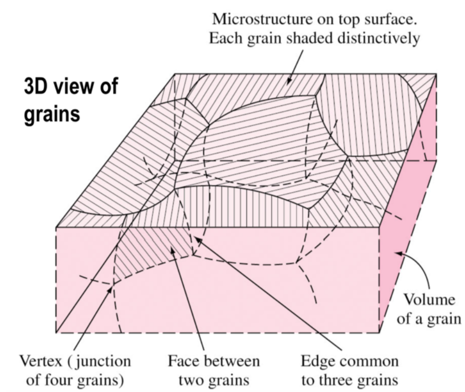


Turbine blades progressed (left to right) from equiaxed, to directional solidified (DS), to single crystal (SX). (Photo courtesy of Howmet Corp.)

Nucleation and crystallization

- Metals are melted then solidified to produce finished and semi-finished parts
- **Grains**: crystals in solidified metals
- Two steps of solidification
  - Nucleation : Formation of stable nuclei
  - Growth of nuclei : Formation of grain structure
- Crystal boundaries are formed when crystals join together at complete solidification, which separates grains
- Thermal gradients define the shape of each grain
- More the number of nucleation sites available, more the number of grains formed, and finer the grains





Types of grains

Equiaxed grains

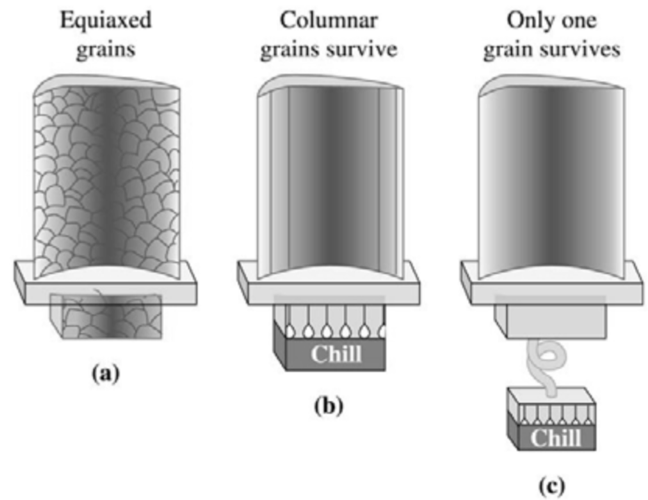
- Crystals grow equally in all directions
- Formed at the sites of high concentration of nuclei
- Commonly formed adjacent to cold mold wall

Alloy contains carbon, boron, zirconium

- Segregate preferentially to grain boundaries
- Provide high-temperature high-boundary strength and ductility for creep resistance

Columnar grains

- Long, thin, and coarse
- Grow predominantly in one direction
- Formed at the sites of slow cooling and steep temperature gradient
- Better creep and fracture resistance



Grains structures in turbine blades:

(a) Conventional equiaxed grains

(b) Directionally solidified columnar grains

(c) Single crystal (SX)

Manufacturing of a single crystal blade
Air-cooled blades

Manufacturing of a single crystal blade

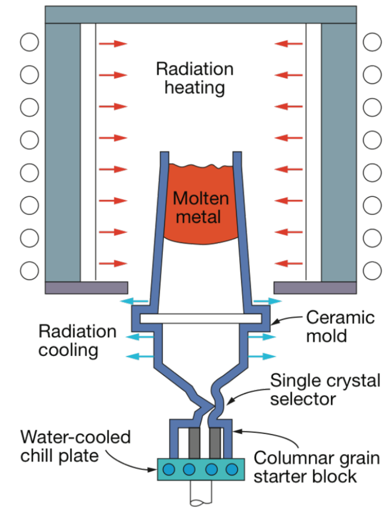
Single crystal blade

Directional solidification

- Pouring molten superalloy metal into a vertically mounted mold heated to metal melt temperature
- Latent heat of solidification is removed by a water-cooled copper chill plate at the bottom of the mold
- The ceramic mold is surrounded by a temperature-controlled enclosure to to keep the sides of the mold at a constant temperature which prevent localized crystallization

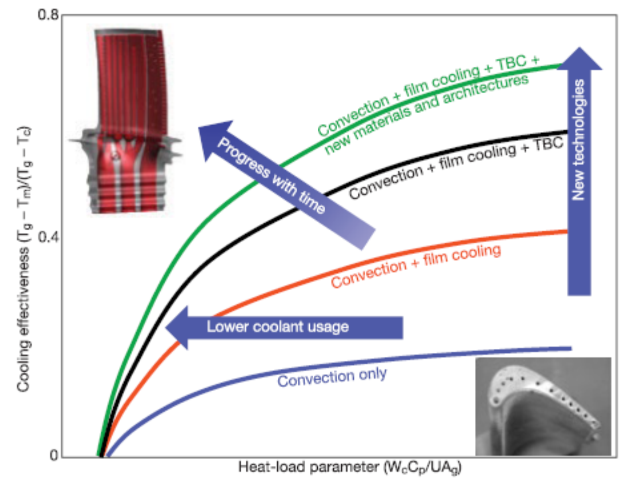
Single crystal

- Number of crystals reduces if a right-angle bend is put a short distance above the chill plate in the casting mold
- "Pigtail": single crystal selector
  - A helical channel with smooth continuous turnings
  - Admitting columnar crystals from the starter
  - Letting just one crystal rise above the helix and start to form the entire blade



Summary

- Turbine blades are exposed to high temperature gas flows and suffered from high stresses, which may lead to creep failure
- To prevent creep, increase the life, and improve efficiency, various cooling techniques and advanced materials are applied in turbine blade designs
- Single crystal technique removes the grain boundaries which effectively improves the life in terms of creep strength and thermal fatigue resistence



2. Notional component cooling technology curves reveal progress over time—from the earliest gross effectiveness of about 0.1 to current levels as high as 0.7. This progression has occurred because of improvements in technology, or the introduction of new technologies, (vertical movement) combined with reductions in coolant usage (movement to left)