OUTLINE

• Historical perspective
• Applications
• Compositions
• Processes
• Properties
  - Creep
Figure 11-16 Genesis of nickel alloy microstructure, 1940 to 1970. Plot shows stress capability of the alloys as a function of approximate date of issue. Structure shown is as heat-treated for best rupture properties; major features only. Compositions are generalized and typical. (X10,000.) (After C. T. Sims and W. C. Hagel, “The Superalloys,” Wiley, New York, 1972, p. 37. Used by permission of John Wiley & Sons, Inc.)
Applications

• Gas Turbine Engines
  – Blades, vanes, disks, combustors

• Space Vehicles
  – Rocket motors

• Nuclear Reactors

• Submarines

• Petroleum Equipment
Compositions

- Ni, Co and Fe Based Alloys
- Solid solution strengthening
  - Cr, Mo, Al, Nb, Ti and others
- Precipitation strengthening
  - Mostly due to Al and Ti
  - $\text{Ni}_3(\text{Al,Ti})$, gamma prime
  - Lattice mismatch, amount, size and morphology
- Carbide phases
  - $\text{M}_{23}\text{C}_6$, $\text{M}_6\text{C}$ or $\text{MC}$
  - M can be Cr, Ti, Mo or W
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<th>Alloy</th>
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<th>% Cr</th>
<th>% Co</th>
<th>% Mo</th>
<th>% Al</th>
<th>% Ti</th>
<th>% Cb</th>
<th>% C</th>
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**Cast alloys**

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**Fig. 20.23** The technique used to obtain monocystal high-temperature turbine blades. (From Kear, B. H., *Scientific American*, October, 1986.)
Fig. 20.22  Comparison of the creep properties at 1255 K and 207 MN/m² of MAR-M200 in the conventionally cast, columnar-grain, and monocrystalline forms. (From Sahm, P. R., and Speidel, M. O., High Temperature Materials in Gas Turbines, Elsevier Scientific Publishing Company, New York, 1974.)
Background of fine $\gamma'$

Twinning

Grain boundary with $M_{23}C_6$ carbides present

MC carbides

$\gamma'$ from carbide degeneration

MC carbide

Matrix usually roughened with "cooling" $\gamma'$

$M_{23}C_6$

Grain boundary $\gamma'$

2850X wrought alloy structures

285X
Dendrite "backbone"

High density of $\gamma'$

$M_{23}C_6$

$\gamma'$ from the melt

Primary MC particle

$\gamma'$ nodule

Normal $\gamma'$

Cooling $\gamma'$

MC script

$\gamma'$ film

$M_{23}C_6$

57X

2850X

Cast alloy structures
Astroloy Microstructure (orig. 15 K X)
CREEP

- Deformation at high temperature under constant load
- Important property of Superalloys
- Brief discussion now, more next time
Figure 13-4 Typical creep curve showing the three steps of creep. Curve A, constant-load test; curve B, constant-stress test.

Figure 13-5 Andrade’s analysis of the competing processes which determine the creep curve.
CORRELATIONS BETWEEN HIGH-TEMPERATURE CREEP AND STRUCTURE

CODE FOR FCC METALS
- Al(a)
- Al(b)
- Al(c)
- Al(d) SINGLE CRYST.
- Ni(a)
- Ni(b)
- Ni(c)
- Cu(a)
- Cu(b)
- Cu(c)
- Ag(a)
- Ag(b)
- Ag(c)
- Ag(d)
- Pt(a)
- Pt(b)
- Au
- Pb
- γ-Fe

\[
\frac{\dot{\varepsilon} kT}{D G b}
\]

\[
\sigma / G
\]

Fig. 3. Steady-State Creep Rates of Nominal Pure FCC Metals Correlated by Eq. 4.
\[
\frac{\dot{\varepsilon}_s k T}{D G b} = A_c \left( \frac{\sigma}{G} \right)^n
\]

\dot{\varepsilon} = \text{STEADY STATE CREEP RATE}

k = \text{BOLTZMANN CONSTANT}

T = \text{ABSOLUTE TEMPERATURE}

A_c = \text{DIMENSIONLESS CONSTANT}

\sigma = \text{APPLIED STRESS}

D = \text{DIFFUSIVITY}

G = \text{SHEAR MODULUS}

b = \text{BURGER'S VECTOR}

n = \text{STRESS EXPONENT (4.2 - 7)}
Fig. 4 Stress-rupture curves for 1000-h life of selected nickel base alloys

Temperature, °C

TRW 1900

Udimet 7000

MAR-M 200

IN-738

IN-100 and B-1900

Approximate stress-rupture range for wrought Ni-base superalloys

Udimet 700
Stress, 1,000 psi

\[ P = (T + 460)(\log t + 20) \times 10^3 \]

- ○ = 1,400°F
- × = 1,500°F
- △ = 1,600°F
- ● = 1,700°F
- □ = 1,800°F
The Larson-Miller Parameter:

Stress Rupture Data Plotted according to the following equation:

\[ \log t = \log \theta + \frac{M Q}{R T} \]

Where \( M = \log e \)

and \( \theta = t \exp (-Q/RT) \)

assuming that \( Q \) and \( \theta \) are function time to rupture or a time to a given

**Table 13.3 Time compression of operating conditions based on Larson-Miller parameter \( C_1 = 20 \)**

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<thead>
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<th>Larson-Miller test conditions</th>
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<td>10,000 h at 1000°F</td>
<td>13 h at 1200°F</td>
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Figure 13-19 Stress plotted according to the equation 

Table 13.3 Time compression of operating conditions
Assignment

• Please email me a question about superalloys before Monday, 17 November

• jacobsonla@att.net

• More about creep next time, and Materials Selection for Design