

MSE200

Lecture 10 (CH. 7.3-7.4)

Mechanical Properties II

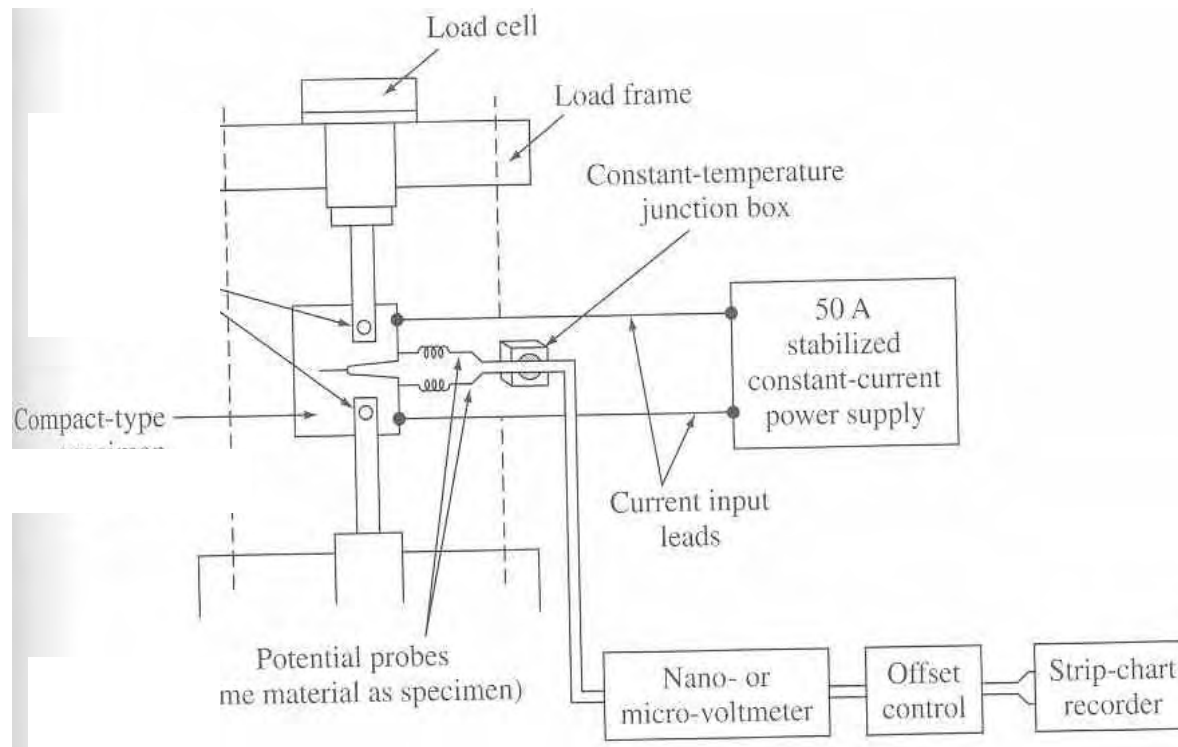
Instructor: Yuntian Zhu

•Objectives/outcomes: You will learn the following:

- Crack growth rate during fatigue.
- Fatigue life of cracked components.
- Stages of creep.
- Effect of stress and temperature on creep behavior. The Larsen-Miller parameter.

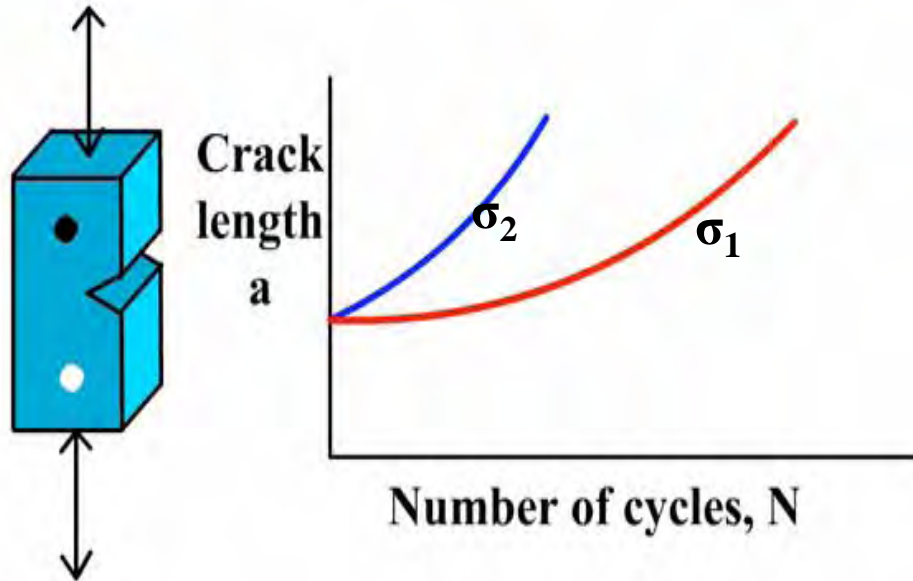
Fatigue Crack Propagation Rate

- **Notched specimen used.**
- **Cyclic fatigue** action is generated.



<http://www.youtube.com/watch?v=sctQ4QRn65Y>

Stress & Crack Length ↔ Fatigue Crack Propagation.



- When 'a' is small, da/dN is also small.
- da/dN increases with increasing **crack length**.
- Increase in σ increases crack growth rate.

$$\frac{da}{dN} = \text{fatigue crack growth rate.}$$

$$\frac{da}{dN} = A \Delta K^m$$

$$\Delta K = K_{\max} - K_{\min} = \sigma_r \sqrt{\pi a}$$

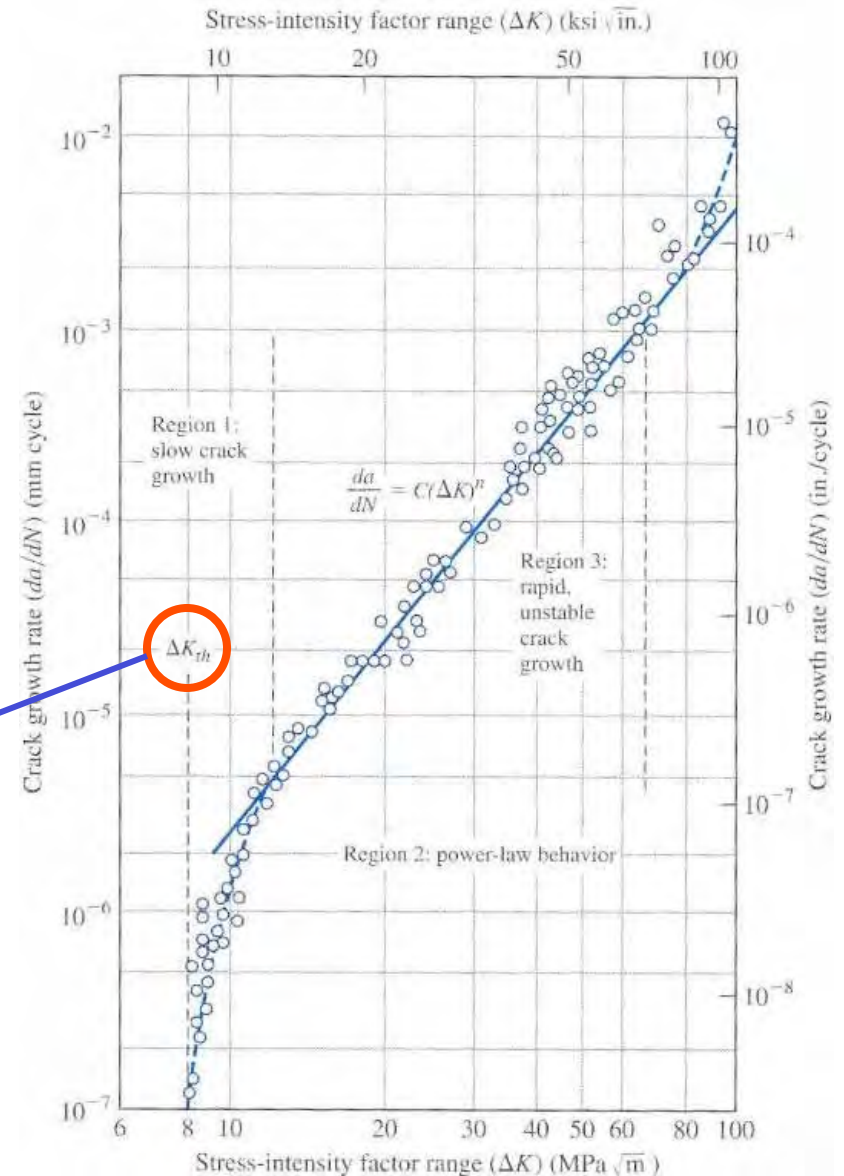
A, m = **Constants** depending on material, environment, frequency temperature and stress ratio.

Fatigue Crack Growth rate Versus ΔK

$$\begin{aligned} \text{Log}\left(\frac{da}{dN}\right) &= \text{Log}(A\Delta K^m) \\ &= m\text{Log}(\Delta K) + \text{Log}(A) \end{aligned}$$

➔ **Straight line with slope m**

Limiting value of ΔK below which there is no measurable Crack growth is called stress intensity factor range threshold ΔK_{th}



Fatigue Life Calculation

$$\frac{da}{dN} = A\Delta K^m$$

But $\Delta K = Y\sigma\sqrt{\pi a}$

Therefore $\Delta K^m = y^m \sigma^m \pi^{\frac{m}{2}} a^{\frac{m}{2}}$

Therefore $\frac{da}{dN} = A(y^m \sigma^m \pi^{\frac{m}{2}} a^{\frac{m}{2}})$

Integrating from initial crack size a_0 to final crack size a_f at number of fatigue cycles N_f

$$\int_{a_0}^{a_f} a^{-\frac{m}{2}} da = Ay^m \sigma^m \pi^{\frac{m}{2}} \int_0^{N_f} dN$$

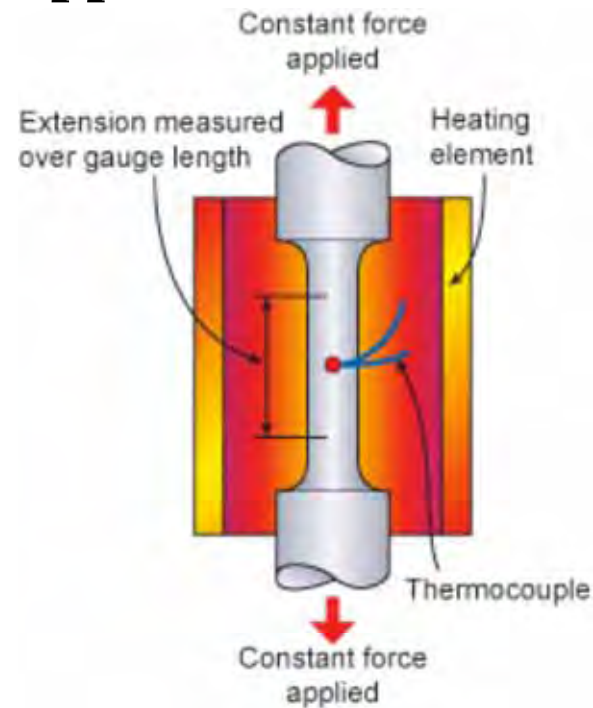
Integrating and solving for N_f 

$$N_f = \frac{a_f^{1-\frac{m}{2}} - a_0^{1-\frac{m}{2}}}{Ay^m \sigma^m \pi^{\frac{m}{2}} \left(1 - \frac{m}{2}\right)}$$

(Assuming Y is independent of crack length)

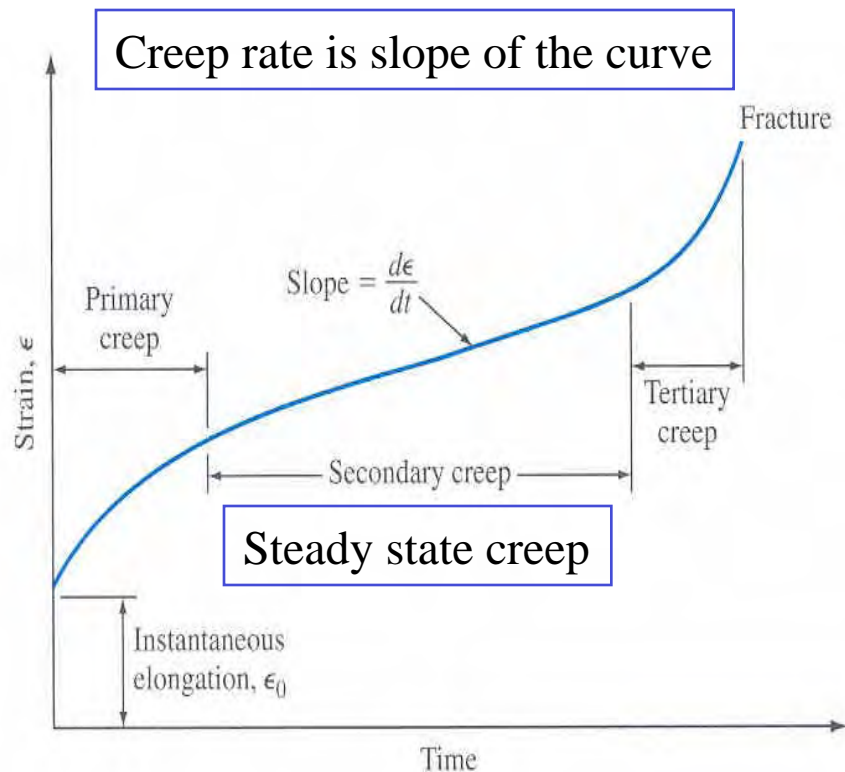
Creep in Metals

- Creep is **progressive deformation** under constant stress.
- Important in high temperature applications.



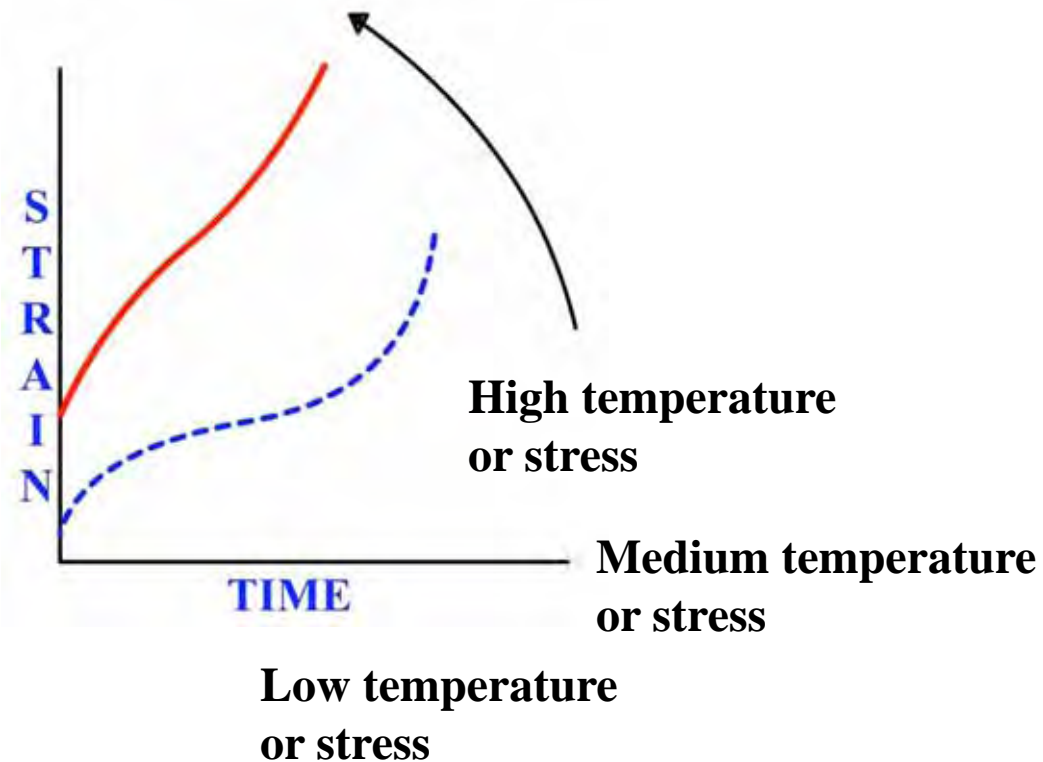
3 stages in creep

- **Primary creep:** creep rate decreases with time due to strain hardening.
- **Secondary creep:** Creep rate is constant due to simultaneous strain hardening and recovery process.
- **Tertiary creep:** Creep rate increases with time leading to necking and fracture.

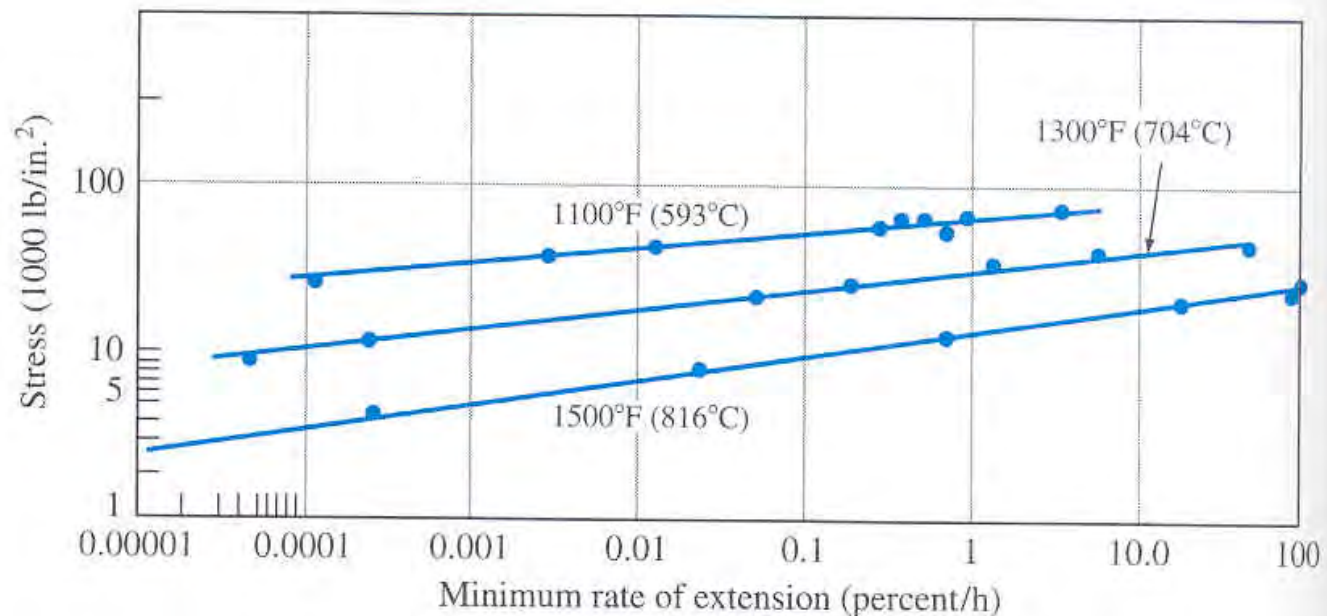


Creep Test

- Metals are tested at **constant stress** at different temperature & constant temperature with different stress.



Creep strength

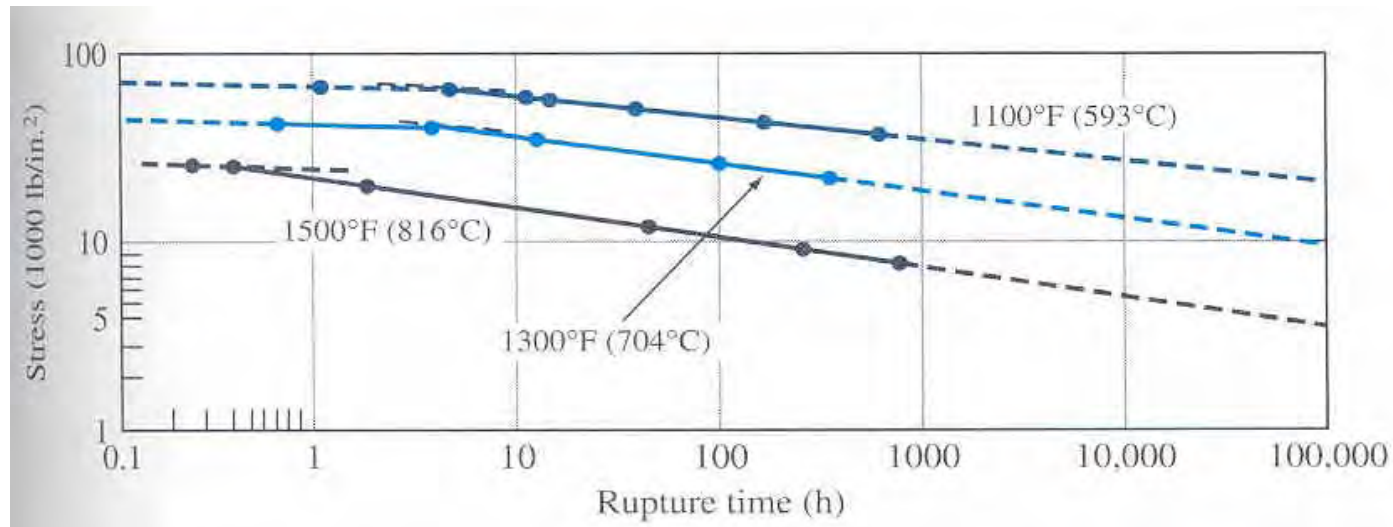


Creep strength: Stress to produce a creep rate of $10^{-5}\%$ /h at a given temperature.

Creep rate means steady state creep rate

Creep Test (Cont..)

- **Creep rupture test is same as creep test but aimed at **failing** the specimen.**



Larsen Miller Parameter for Rupture creep

- ***Larsen Miller parameter*** is used to represent creep-stress rupture data.

$$P(\text{Larsen-Miller}) = T[\log t_r + C]$$

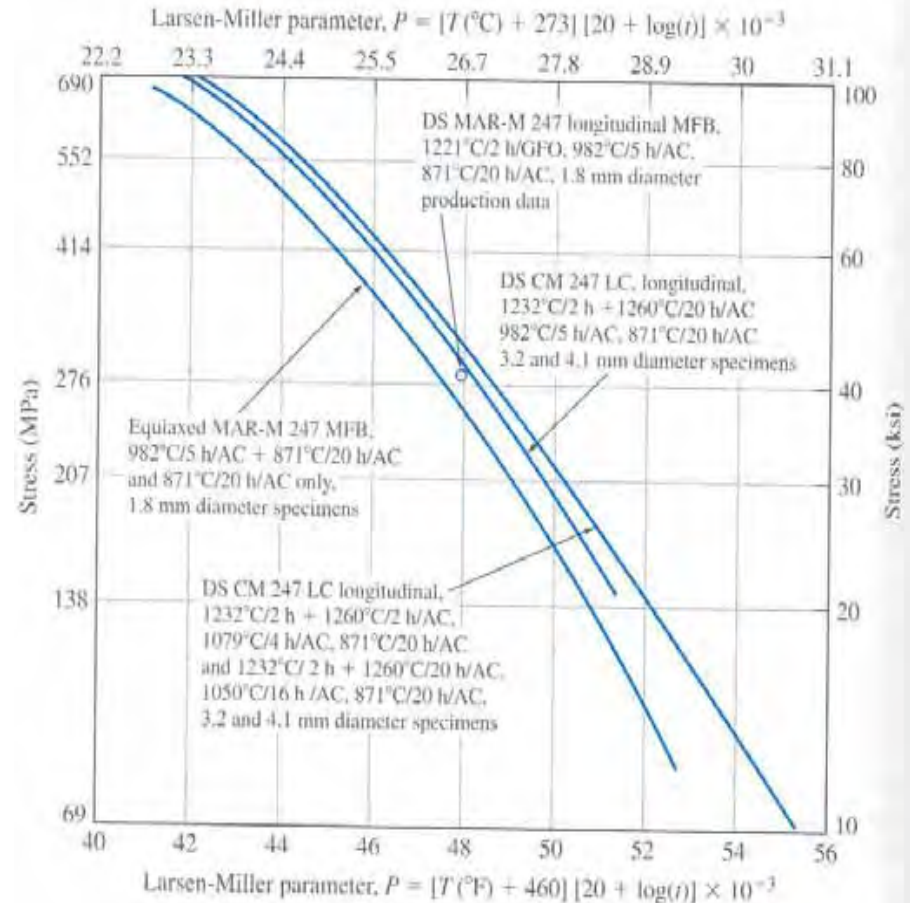
T = temperature(K), t_r = stress-rupture time h

C = Constant (order of 20)

Larsen Miller Parameter

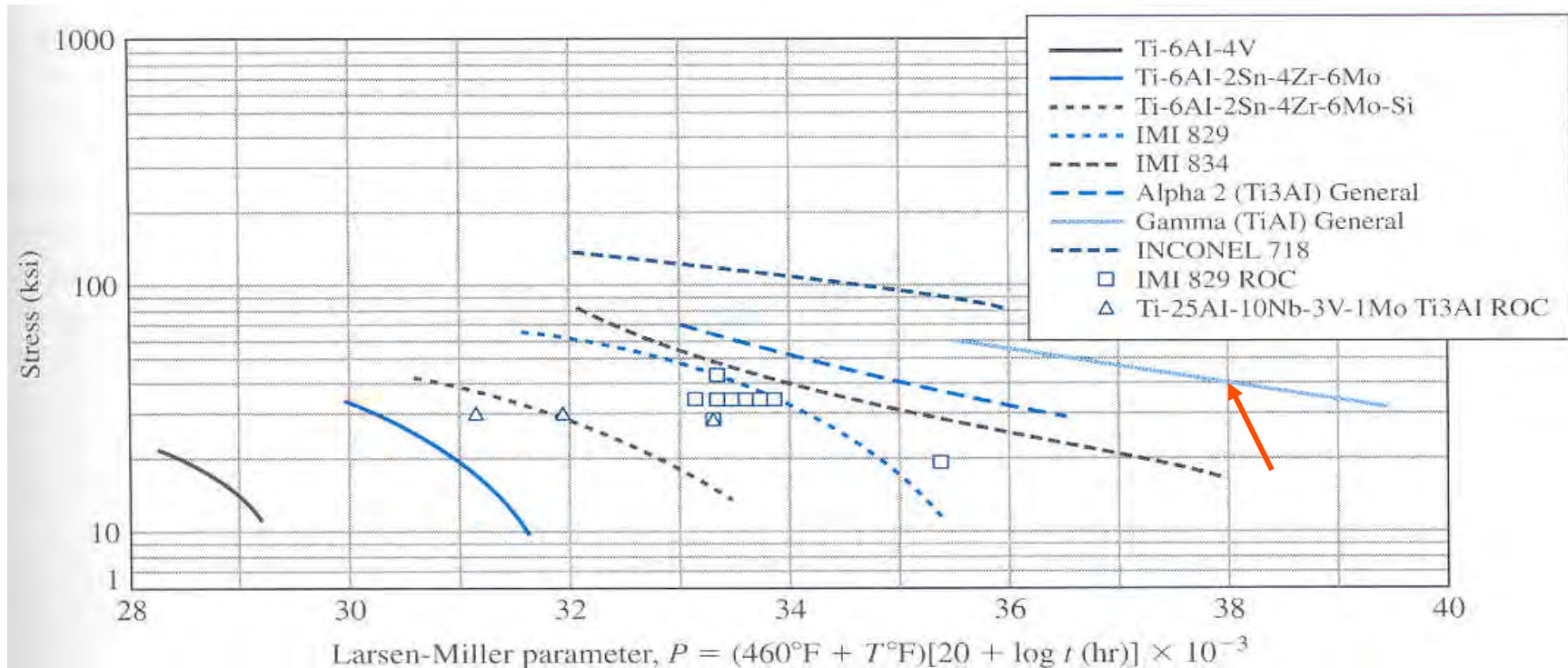
If two variables of **time** to rupture, **temperature** and **stress** are known, 3rd parameter that fits L.M. parameter can be determined.

$$P = T[\log t_r + 20]$$



P is a function of stress

L.M. Diagram of several alloys/examples



Example: Calculate time to cause rupture in gamma Titanium aluminide at 40 KSI and 1200°F

From fig, $p = 38000$

$$P = T[\log t_r + C]$$

$$38000 = (1200 + 460) (\log t + 20) \longrightarrow t=776 \text{ h}$$

Creep rate is usually controlled by Diffusion of atoms

- Factors affecting creep rate:

Homework

- Example problems: 7.2, 7.3, 7.4, 7.5
- Chapter 7: 31, 33
- Reading assignment for next lecture on March 9 (after Test 2): Chapter 8.1-8.4