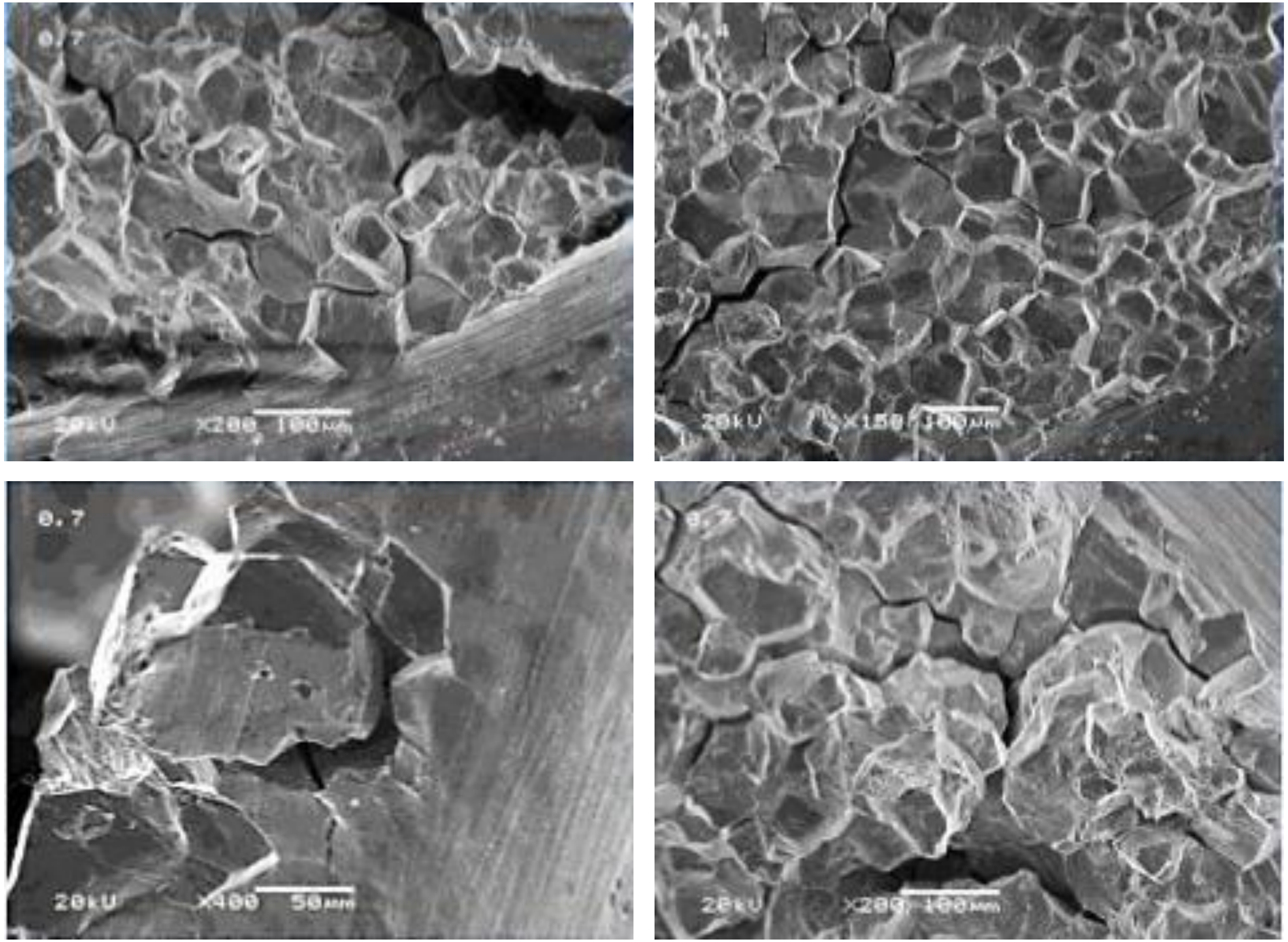


To avoid creep failure:

Creep is minimized in materials with:

1. High melting temperature
2. High elastic modulus
3. Large grain sizes

Materials which especially resilient to creep:

1. Stainless steel
2. Refractory metals (containing elements like Nb, Mo. Ta. W)
3. Super alloys (**WHAT ?**)

Correlation and Extrapolation Methods

- Engineers have to **confirm** to customers that a particular component will **with stand usage** at elevated temperatures for a particular life-time.
- One solution to this problem involves performing creep and/or creep rupture tests at temperatures in excess of those required, for shorter time periods, and at a comparable stress level, and then making a suitable extrapolation to the in-service condition.
- The most well-known method is that of **Larson** and **Miller** and is based upon the Arrhenius equation:

$$\log_{10} t_r = \log_{10} G + 0.4343\ \frac{Q_c}{R}\frac{1}{T}$$

where t_r is the time to rupture (lifetime rupture) and G is constant. The activation energy for creep, Q_c is assumed to be stress-dependent;

$$\therefore \log_{10} t_r + C = m\frac{1}{T}$$

OR

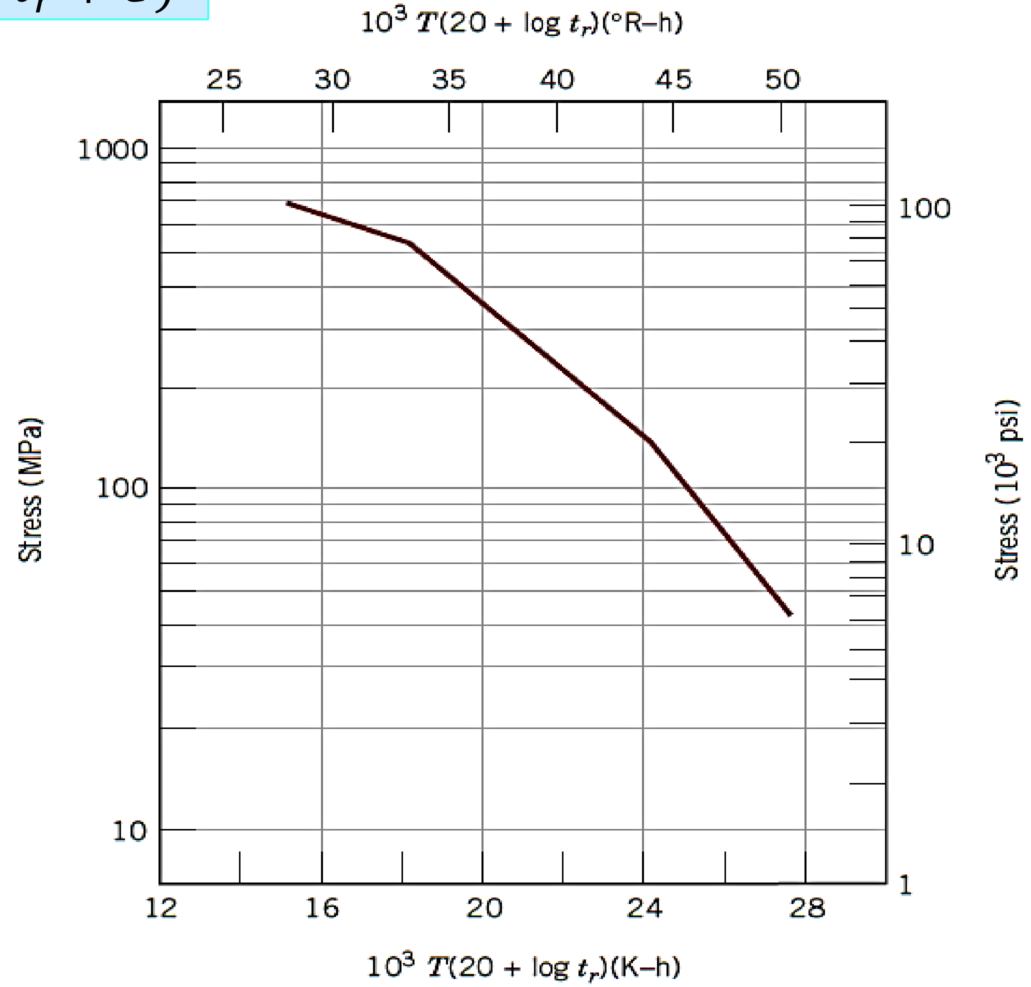
$$\therefore\ T(\log_{10} t_r + C) = m$$

This can be written as: $P_1 = m = f(\sigma)$

where the **Larson-Miller** parameter $\therefore P_1 = m = T(\log_{10} t_r + C)$

- The rupture lifetime of a given material measured at some specific stress level will vary with temperature such that this parameter remains constant.
- The value of the constant C can be obtained from the intercept when $\log_{10} t_r$ is plotted against $1/T$.
- **Sherby and Dorn**, suggest that G is not a true constant but varies with stress whilst E is essentially constant. If 0.4343 Q_c/R is replaced by α and $\log_{10} G$ by ϕ then this equation can be written as:

$$\log_{10} t_r - \frac{\alpha}{T} = \emptyset$$



This can be written as: $P_2 = \emptyset = f(\sigma)$

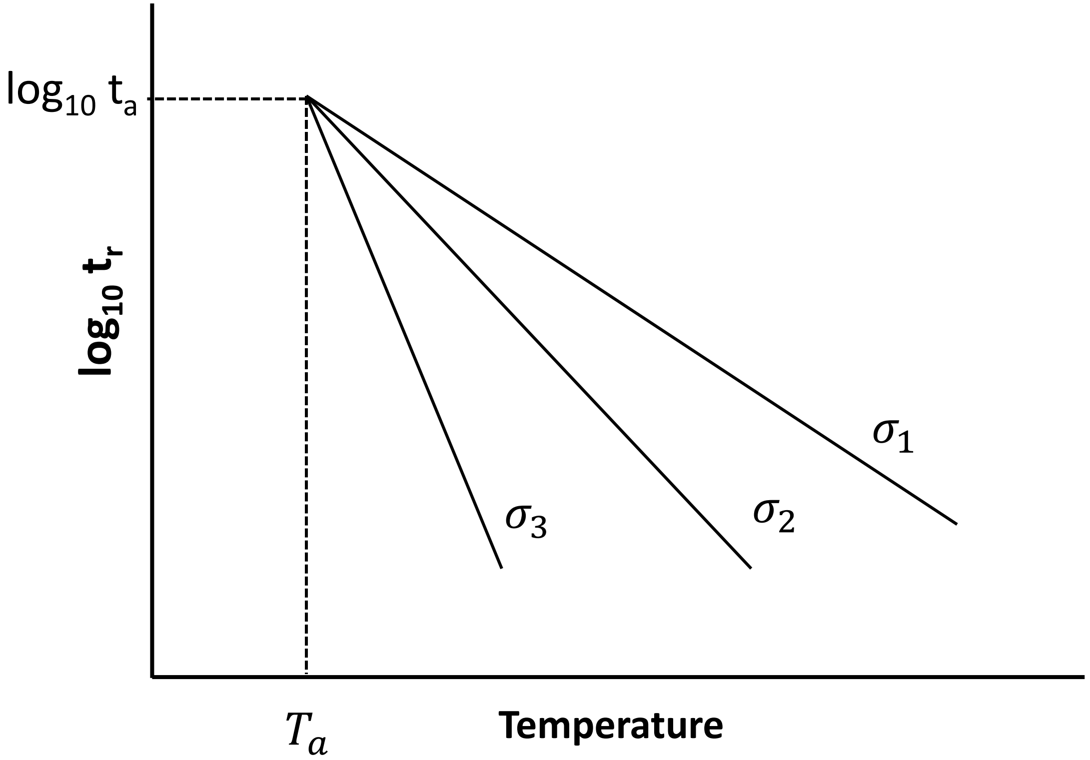
where the **Sherby and Dorn** parameter $P_2 = \log_{10} t_r - \frac{\alpha}{T}$

- The constant α can be determined from the common slope of a plot of $\log_{10} t_r$ versus $1/T$.

- **Manson and Haferd** who found that, for a given material under different stress and temperature conditions, a family of lines was obtained which intercepted at a point when $\log_{10} t_r$ was plotted against T. These lines can be represented by:

$$T - T_a = m\,(log_{10}t_r - log_{10}t_a)$$

This can be written as: $P_3 = m = f(\sigma)$



The Manson-Haferd parameter

$$P_3 = \frac{T - T_a}{\log_{10} t_r - \log_{10} t_a}$$

- The table presents estimated values for the three parameters for a number of engineering alloys.

Materials	Sherby–Dorn Q, (kJ/mol.)	Larson-Miller C	Manson–Haferd	
			T_a (˚K)	log t_a
Various steels and stainless steels	≈400	≈20	----	----
Pure aluminium and dilute alloys	≈150	----	----	----
Nimonic 81A (Ni-based)	380	18	311	16
1% Cr - 1% Mo -0.25%V steel	460	22	311	18
A-286 stainless steel	380	20	367	16

Example

Calculate the time to rupture at 650◦C and 100MPa stress for a 1%Cr-1% Mo-0.25%V steel, according to the Larson-Miller , Sherby--Dorn, and Manson--Haferd methods, if this alloy underwent rupture in 20hrs when tested in tension at the same stress level at a temperature of 750◦C.

Solution

The **Larson-Miller** equation is

T (log tr + C) = m.

At 750˚C, T = 750 + 273 = 1,023˚K and tr = 20 hours, we have;

$m = 1023 \times (\log 20 + 22) \approx 2.4 \times 10^4$

At 650˚C, T = 650 + 273 = 923˚K, we have;

$923(\log tr + 22) = 2.4 \times 10^4$ $\log tr = (2.4 \times 104/923) - 22$

$tr = 6.7 \times 10^3$ hours.

The **Sherby-Dorn** equation is

log tr – 0.43(Q/RT) = m

From Table 1, Q = 460 kJ/mol.

At 750◦C, T = 1,023˚K and tr = 20 hours. We have,

m = log 20 – 0.43(460 × 10^3 /(8.314 × 1023))

At 650˚C, T = 923˚K, and we obtain log tr = m + 0.43(Q/RT)

so that **tr = 6.6 × 10^3 hours**.

The **Manson-Haferd** equation is

(T − Ta)/(log tr − log ta)= m. From Table 1, Ta =311˚K, and log ta = 18.

At 750◦C, T = 1,023˚K, and it follows that tr = 20 hours.

Therefore, m = (1023 − 311)/(log 20 − 18)= − 42.64.

At 650◦C, T = 9230 ˚K, and we have (T − Ta)/(log tr − log ta)= m

(923 − 311)/(log tr − 18) = −42.64, log tr = 3.64,

tr = 4.4 × 10^3 hours.

Stress Relaxation

- An important engineering situation involves cylinder-head bolts, rivets in pressure vessels operating at elevated temperatures, where the strain is considered to be constant and then the decrease in stress, which may take place, is required to be evaluated.
- This time-dependent decrease in stress under constant strain conditions is called "stress **relaxation**"
- Consider two plates held together by a bolt deformed by a stress $\boldsymbol{\sigma_i}$ producing an initial strain $\boldsymbol{\epsilon_i}$ which is all elastic. Then:

$$\epsilon_i = \epsilon_e = \frac{\sigma_i}{E}$$

- At elevated temperature and under conditions of steady-state creep, $\dot{\epsilon} = \frac{d\epsilon_c}{dt} = K\sigma^n$

the strain caused by creep ϵ_c simply reduces the elastic part ϵ_e of the initial strain,

$$\epsilon_e = \epsilon_i - \epsilon_c$$

$$\therefore \frac{d\epsilon_e}{dt} = -\frac{d\epsilon_c}{dt} \Rightarrow \therefore \frac{1}{E}\frac{d\sigma}{dt} = -K\sigma^n \Rightarrow \therefore \int \frac{d\sigma}{\sigma^n} = -EK\int dt$$

$$\therefore -\frac{1}{(n-1)\sigma^{n-1}} = -EKt + C$$

To find C, consider the time $t = 0$, when the stress would be the initial stress σ_i. Then

$$\therefore -\frac{1}{(n-1)\sigma_i^{n-1}} = C$$

$$\frac{1}{\sigma^{n-1}} = \frac{1}{\sigma_i^{n-1}} + KE(n-1)t$$