10. Creep Life Prediction: Creep tests take a long time to perform making the generation of design data expensive and the lead time between developing a new alloy and its exploitation excessive. The fact that there is an Arrhenius relation between creep rate and temperature has led to a number of time-temperature parameters to be developed which enable extrapolation and prediction of creep rates or creep rupture times to longer times than have been measured. They also enable rating comparisons to be made between different materials. It is important that no structural changes occur in the region of extrapolation, but since these would occur at shorter times for higher temperatures it is safer to predict below the temperature for which data is known than above. One parameter used is the **Larson-Miller Parameter**.

This is derived by taking natural logs of the Arrhenius equation: $\dot{\varepsilon} = A\exp-\left(\frac{Q}{kT}\right)$

(Note that k is being used here instead of R so that Q is quoted in joules per atom. Also, if logs to the base 10 are used, the Larson-Miller Constant values given below are multiplied by $\log_{10}e = 0.43429$)

$\ln\dot{\varepsilon} = \ln A - \frac{Q}{kT}$, $\therefore \ln A - \ln\dot{\varepsilon} = \frac{Q}{kT}$. If we assume that the creep strain to rupture ε_r is a constant over the temperature range of interest, and the major part of the creep strain is steady state creep, then the average creep rate over the life to rupture, t_r, of the specimen is: $\dot{\varepsilon} = \frac{\varepsilon_r}{t_r}$.

$$\therefore \ln A - \ln\left(\frac{\varepsilon_r}{t_r}\right) = \ln A - \ln\varepsilon_r + \ln t_r = \frac{Q}{kT}$$

$\therefore T(C_1 + \ln t_r) = \frac{Q}{k} = P$ ...(11), where $C_1 = \ln A - \ln t_r$ is the Larson-miller Constant and P is the Larson-Miller Parameter for a particular stress, since $Q = (Q_0 - v\sigma)$. Plotting experimental data of $\ln t_r$ versus $\frac{1}{T}$ gives a straight line with slope P and intercept at $\frac{1}{T} = 0$ of $-C_1$. The values of C_1 range from 35 to 60, but is typically 46, and Figure 26 shows that it is independent of stress.

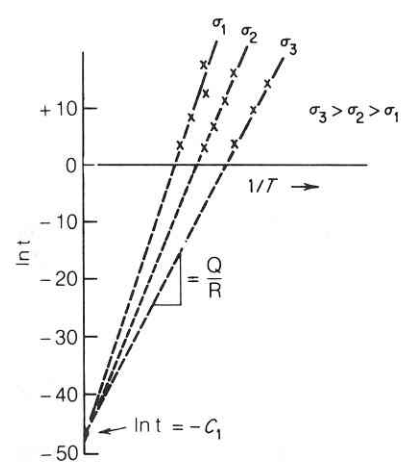
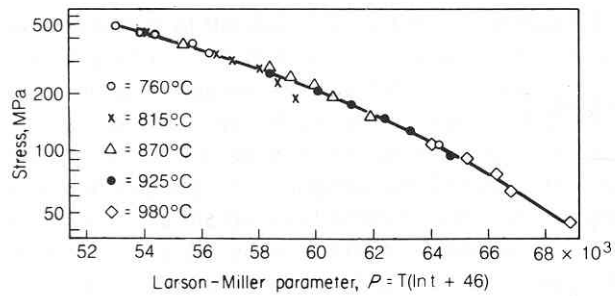


Figure 26: Stress rupture data plotted as ln(rupture time) versus reciprocal of absolute temperature.

Figure 27: Shows a plot of stress versus Larson-Miller Parameter for the alloy Astroloy.



It is clear that for a given stress, the Larson-miller Parameter for the material can be obtained and the time to rupture predicted for any temperature. Alternatively, given a lifetime required at a specified temperature, the L-M Parameter can be calculated and the maximum allowed stress looked up on a graph like Figure 26. E.g., For a 100,000 hour life at 870°C (1143 K), P = 1143(ln10^5 + 46) = 65.7.10^3. This corresponds to a stress of 85 MNm^{-2}.

In practice, alloys used in applications like turbine blades experience a wide range of stresses and temperatures for varying times during start-up, take-off, steady flight, landing and shut-down. Creep strains accumulate during these stages and design could assume a 'worst case' scenario, but this would lead to a weight penalty in the aero-engine and less payload. Alternatively, an approach similar to Miner's Law in fatigue can be adopted, and this is called the **'Life fraction rule'.** This states that rupture occurs when the sum of all the fractions of the rupture life at different stress/temperature combinations becomes equal to unity. I.e.

$$\sum\left(\frac{t_1}{t_{R1}}+\frac{t_2}{t_{R2}}+\frac{t_3}{t_{R3}}.....\right)=\sum_i\frac{t_i}{t_{Ri}}=\int\frac{1}{t_R}dt=1$$ ....(12), where t_i is the time spent at a particular stress/ temperature combination where the time to rupture is t_{Ri}. The data in Figure 9 can be used to carry out such a calculation.