

Question 1:

A sample was examined using NDT and found to have a 2 mm long surface crack. The sample material has m and A values of 3.4 and 2.0×10^{-7} respectively for stress in 'MPa' and crack length in 'm' yielding crack propagation rate in 'mm/cycle'. The sample would be repeatedly subjected to a maximum stress of 150 MPa in tension and a minimum stress of 50 MPa in compression.

- Determine the fatigue crack propagation rate in mm/cycle for the given stresses.
- Would the crack propagation rate be the same if the sample was subjected to a minimum stress of -20 MPa instead of -50 MPa? Briefly explain.

Assume that the dimensionless parameter Y has a value of 1.5

Solution:

Given, $a = 2.0 \text{ mm} = 2 \times 10^{-3} \text{ m}$

$m = 3.4$; $A = 2.0 \times 10^{-7}$; $Y = 1.5$

(a)

$\sigma_{\max} = 150 \text{ MPa}$ and $\sigma_{\min} = -50 \text{ MPa}$

The crack propagation rate, $\frac{da}{dn} = A(\Delta k)^m$

$$\Delta k = Y \Delta \sigma \sqrt{\pi a} = Y (\sigma_{\max} - \sigma_{\min}) * \sqrt{(\pi a)}$$

Here, $\sigma_{\min} = 0$ (Since, compressive)

$$\Delta k = Y * 150 \sqrt{\pi * 2 * 10^{-3}} = 17.83 \text{ Mpa} \cdot \text{m}^{\frac{1}{2}}$$

$$\frac{da}{dn} = 2.0 \times 10^{-7} (17.83)^{3.4} = 0.0036 \text{ mm/cycle}$$

Fatigue crack propagates at a rate of $3.6 \times 10^{-3} \text{ mm/cycle}$.

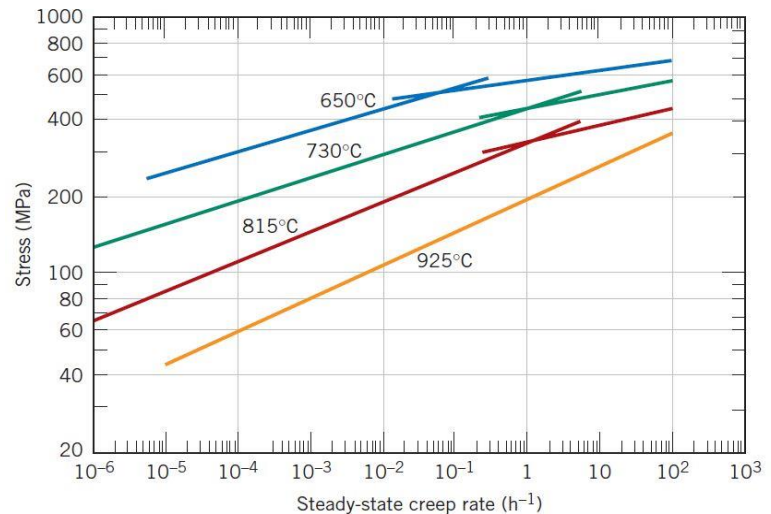
(b)

Yes, the fatigue crack propagation rate would be the same in case of a minimum stress of -20 MPa instead of -50 MPa. The rate is going to be the same for all compressive stresses because compressive stresses do not contribute to the opening or propagation of fatigue cracks.

Question 2:

A cylindrical specimen 13.2 mm in diameter of an S-590 alloy is to be subjected to a tensile load of 27,000 N. At approximately what temperature will the steady state creep be 10^{-3} h^{-1} ? Use the data shown in the accompanying figure for S-590 alloy.

Assume the stress exponent, n , to be independent of temperature.

**Solution:**

Given $d = 13.2 \text{ mm}$ and $F = 27,000 \text{ N}$

Applied stress:

$$\sigma = \frac{F}{A_0} = 197.3 \text{ MPa} (= 200 \text{ MPa})$$

Since we can get two sets of values from the graph corresponding to 2 different temperatures and σ being the same can be treated as a constant in this problem. K_2 & n are material based constants, we can now take $K'_2 = K_2 \sigma^n$. We now have 2 equations and 2 unknowns (Q_c and K'_2).

$$\dot{\epsilon}_s = K_2 \sigma^n \exp\left(-\frac{Q_c}{RT}\right) = K'_2 \exp\left(-\frac{Q_c}{RT}\right)$$

Taking natural logarithms of the above equation

$$\ln \dot{\epsilon}_s = \ln K'_2 - \frac{Q_c}{RT}$$

We have two unknowns Q_c and K'_2 , and therefore have to get at least two data points from the graph:

$$\text{@ } 200 \text{ MPa, } T_1 = 730^\circ\text{C} = 1003 \text{ K} \rightarrow \dot{\epsilon}_s = 1.8 \times 10^{-4} \text{ h}^{-1}$$

$$T_2 = 815^\circ\text{C} = 1088 \text{ K} \rightarrow \dot{\epsilon}_s = 1.5 \times 10^{-2} \text{ h}^{-1}$$

Solving for Q_c and K'_2

$$Q_c = -\frac{R(\ln \dot{\epsilon}_{s1} - \ln \dot{\epsilon}_{s2})}{\frac{1}{T_1} - \frac{1}{T_2}}$$

At 200 MPa,

$$Q_c = -\frac{(8.31 \frac{\text{J}}{\text{mol}\cdot\text{K}})[\ln(1.8 \times 10^{-4}) - \ln(1.5 \times 10^{-2})]}{\frac{1}{1003 \text{ K}} - \frac{1}{1088 \text{ K}}} = 471,861 \text{ J/mol}$$

$$K'_2 = \dot{\epsilon}_{s1} \exp\left(\frac{Q_c}{RT}\right) = (1.8 \times 10^{-4} \text{ h}^{-1}) \exp\left(\frac{471,861 \text{ J/mol}}{(8.31 \text{ J/mol}\cdot\text{K})(1003 \text{ K})}\right) = 6.95 \times 10^{20} \text{ h}^{-1}$$

To calculate the temperature which yields steady state creep rate of 10^{-3} h^{-1} , we substitute the values in the equation

$$\ln \dot{\epsilon}_s = \ln K'_2 - \frac{Q_c}{RT}$$

$$\ln(10^{-3}) - \ln(6.95 \times 10^{20}) = \frac{-471,861}{(8.31 \frac{\text{J}}{\text{mol}\cdot\text{K}}) T}$$

Solving for temperature, we get $T = 1034 \text{ K} = 761^\circ\text{C}$

Question 3:

A Larson-Miller plot for some hypothetical metal alloy is shown in the following figure. The value of the parameter C is unknown. However it is known that at a stress level of 125 MPa and at 950 K, rupture occurs at 1000 hr. On this basis, calculate the rupture life time at a stress level of 200 MPa and 800 K.

Solution:

For the initial condition: $\sigma = 125$ MPa, $\log(\sigma) = 2.097$. Using the given graph, this value for stress logarithm corresponds to:

$$T(C + \log t_r) \times 10^3 = 19000 \text{ K-hr}$$

$$19000 = 950(C + \log(1000)) \Rightarrow C = 17$$

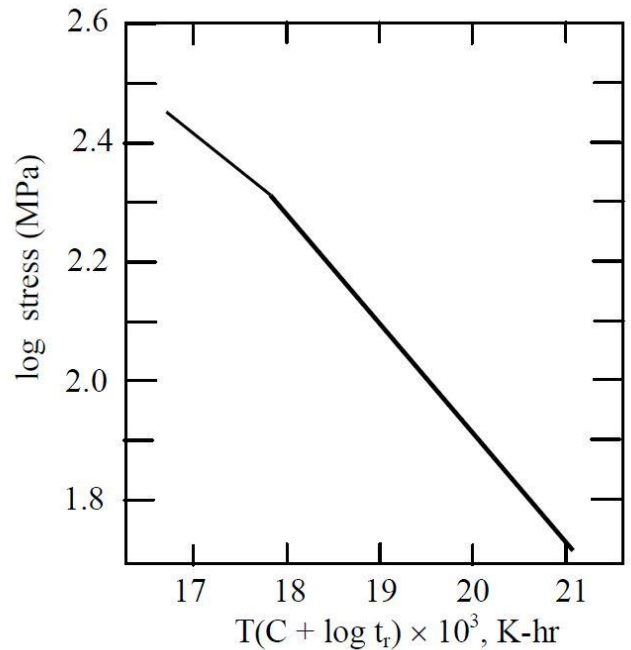
Now, having the value for C , we can calculate the rupture life time at given stress level and temperature. At $\sigma = 200$ MPa and $T = 800$ K; $\log(200) = 2.30$.

Using the given graph, this value for stress logarithm corresponds to:

$$T(17 + \log t_r) \times 10^3 = 17800 \text{ K-hr. Thus:}$$

$$17,800 = T(17 + \log(t_r)) = 800(17 + \log(t_r)) \Rightarrow \log(t_r) = 5.25$$

$$\Rightarrow t_r = 177,828 \text{ hr} = 7049.5 \text{ days} = \sim 20 \text{ years}$$

**Question 4:**

A piece of corroded steel plate was found in a submerged ocean vessel. It was estimated that the original area of the plate was 10 in^2 and that approximately 2.6 kg had corroded away during the submersion. Assuming a corrosion penetration rate of 200 mpy for this alloy in seawater, estimate the time of submersion in years. The density of steel is 7.9 g/cm^3 .

Solution:

This problem calls for us to compute the time (t) of submersion of a steel plate

$$t = \frac{KW}{\rho A (\text{CPR})}$$

Thus, using values for the various parameters given in the problem statement:

$$t = \frac{(534)(2.6 \times 10^6 \text{ mg})}{(7.9 \text{ gr/cm}^3)(10 \text{ in}^2)(200 \text{ mpy})} = 8.8 \times 10^4 \text{ h} = \sim 10 \text{ yr}$$

Question 5:

(a) Creep is a very slow deformation of materials at elevated temperatures and at stresses well below yield strength. Briefly explain what makes creep different from plastic deformation of metals at room temperature.

(b) What part of a nail after being hammered is more susceptible to corrosion? Assume all parts of this nail are equivalently exposed to moisture. Explain your answer?

Solution:

(a) Creep occurs at elevated temperatures and becomes predominant at about $0.4T_m$ for most metals. Creep is a very slow process because it is dependent on diffusion of vacancies or interstitials or both. The temperature dependence of creep is also explained by the diffusion process which is temperature dependent. Hence the strain rate in creep increases with increase in temperature. On the other hand plastic deformation is fairly independent of time and mostly based on dislocation motion and interatomic bonding of atoms at room temperature.

(b) The head of the nail experiences most of cold work done on the nail. Consequently, cold-worked metals are more susceptible to corrosion than non-cold worked metals because of the increased dislocation density of the former. The region in the vicinity of a dislocation that intersects the surface is at a higher energy state, and, therefore, is more readily attacked by a corrosive solution.