Strain-Life Fatigue Design

EXAMPLE Use of Neuber Analysis and Strain-Life Curve

A hot-rolled 4340 steel plate has the following mechanical properties: σ_{ult} = 826 MPa; $\sigma_y = 634\,\text{MPa}; E = 206\,\text{GPa} = 206 \times 10^3\,\text{MPa}; \varepsilon_f' = 0.53; b = -0.10; c = -0.56; n' = 0.17;$ $k' = 1384\,\text{MPa}; \sigma_f' = 1232$ MPa. The plate is loaded in tension by a completely reversed axial force of 500,000 N. The plate has a single edge notch with a fatigue stress concentration factor of K_f = 1.8. At the notch the plate is 20 mm thick and the net width is 101.6 mm.

The nominal stress amplitude is $S_a = \dfrac{P}{A} = \dfrac{500{,}000}{20 \times 101.6} = 246\text{N/mm}^2 = 246\,\text{MPa}.$ Thus, the nominal stress range is $\Delta S = 2S_a = 2(246) = 492\,\text{MPa},$ from Fig. 12.6. From Eq. (12.21)

$$\Delta\sigma\Delta\varepsilon = \frac{(1.8 \times 492)^2}{206 \times 10^2} = 3.8\,\text{MPa}$$

From the relationship for the cyclic stress-strain curve, Eq. (12.16),

$$\frac{\Delta\varepsilon}{2} = \frac{\Delta\sigma}{2(206 \times 10^3)}\frac{\Delta\varepsilon}{\Delta\varepsilon} + \left(\frac{\Delta\sigma}{2 \times 1384}\frac{\Delta\varepsilon}{\Delta\varepsilon}\right)^{1/0.17}$$ and since $\Delta\sigma\Delta\varepsilon$ has been found above to be 3.8 MPa,

$$\Delta\varepsilon = \frac{3.8}{206 \times 10^3}\frac{1}{\Delta\varepsilon} + 2\left[\frac{3.8}{2(1384)}\frac{1}{\Delta\varepsilon}\right]^{5.88}$$

Using iteration to solve for $\Delta\varepsilon$, the strain range is found to be 4.026×10^{-3} mm/mm.

Now we can use the equation for the strain-life curve, Eq. (12.17), to estimate the number of cycles to initiate a fatigue crack, N_i. Substituting the parameters for the strain-life curve,

$$\frac{4.026 \times 10^{-3}}{2} = \frac{1232}{206 \times 10^3}\left(2N_i\right)^{-0.10} + 0.53\left(2N_i\right)^{-0.56}$$

$$2.013 \times 10^{-3} = 5.580 \times 10^{-3}\,N_i^{-0.10} + 0.360N_i^{-0.56}$$ and

$$N_i^{-0.10} = 0.361 - 64.5N_i^{-0.56}$$

$$N_i = \left(0.366 - 65.5N_i^{-0.56}\right)^{-1/0.10}$$

Solving the preceding equation by iteration, the number of cycles to initiate a crack about 1 mm long is 2.104 x 10^5 cycles.