Session 42 Homework – FCG and C(t) Estimation (Primary Loads Only)

Mentor Guide Knowledge & Skills Questions

[1.35] Define the effective stress intensity factor range, ΔK_{eff}, used in R5 fatigue crack growth assessments.

[1.36] Define when plasticity corrections to ΔK_{eff} are required. State the corresponding methodology.

[1.37] Define the ΔK_{eff} based method for calculating fatigue crack growth. State the criterion for this approach to be valid.

[1.38] Discuss the threshold for fatigue crack growth.

[1.39] Discuss the effect of creep dwells on fatigue crack growth rates and when creep-enhanced fatigue laws need be taken into account explicitly in assessments (see also 3.3).

[1.40] Discuss the range of stress or stress intensity factors for which 'Paris law' fatigue crack growth formulations are valid.

[1.41] Describe the method for calculating fatigue crack growth for cracks embedded within the cyclic plastic zone. State how the size of the cyclic plastic zone is determined.

[1.42] State the basic reference stress formula for estimating C* under primary stressing alone.

[1.43] Define "redistribution time", t_{red}, and how it is calculated.

[1.44] Write down the C(t) estimation formula for primary loading alone, in terms of either time or strain. Hence describe how C(t) varies with time under primary stressing alone.

[1.45] Outline how the C(t) estimation formula is modified in the presence of significant plasticity and how this may be taken into account quantitatively within the R5 procedure.

Numerical Question

There is an 'original sin' crack of depth 3mm present in a 316H parent feature of section thickness t = 20mm. The LEFM stress intensity factor is given by,

$$K = (1.12 + 100a)\sigma_0\sqrt{\pi a} \qquad \text{(for } a \text{ in m)}$$

In steady operation the temperature is 525°C and the uncracked Mode I stress is $\sigma_0 = 100$ MPa (primary). However, a trip transient increases the stress briefly to $\sigma_0 = 120$ MPa. Similarly a start-up transient causes a brief compressive stress of $\sigma_0 = -60$ MPa. There are 10 start-up/trip cycles per year. It has been determined that creep is unperturbed by cyclic loading and that a Paris Law is appropriate for fcg.

A reference stress solution has been found to be $\sigma_{ref} = \dfrac{\sigma_0}{1 - a/t}$. The monotonic plastic

strain for a given reference stress is given by $\varepsilon^p_{ref} = \left(\frac{\sigma_{ref}}{485}\right)^5$, and the cyclic plastic strain for a given reference stress range is $\Delta\varepsilon^p_{ref} = \left(\frac{\Delta\sigma_{ref}}{700}\right)^5$. (*Hint: you will need plastic strain for both the creep crack growth and the fatigue crack growth*).

- Use the upper bound ccg law with $A = 0.221$ and $q = 0.891$ (units: MPa, m and hours).
- Use the appropriate upper bound fcg law for 316H parent from R66 (*Hint: since the calculation is from the start of life it is clear that there is no prior creep damage*).
- Use best estimate RCC-MR creep deformation. State whether you are assuming time hardening or strain hardening.
- Assume a creep index, *n*, derived from the value of *q*.
- Use E = 160 GPa.
- Assume a generation factor of 85% (i.e., 7446 hours generation per year).

Find the following,

(i) Calculate the initial fcg rate (expressed in mm/year);

(ii) Calculate the ccg rate after 1 hour (expressed in mm/year);

(iii) By what factor would (i) be *smaller* if plasticity were ignored?

(iv) By what factor would (ii) be *larger* if plasticity were ignored?

(v) Numerically integrate to find the total growth against time. (You may smear fcg uniformly over time or apply it discretely at 1/10 year intervals).

(vi) What is the growth in the 1st, 2nd and 3rd years?

(vii) When does the crack depth reach the critical depth of 12mm?

(viii) What would the growth be in the 1st, 2nd and 3rd years if fcg were ignored? When would the critical crack depth be reached?

(ix) What would the growth be in the 1st, 2nd and 3rd years if ccg were ignored? When would the critical crack depth be reached?

(x) Comment on the difference between the result (vi) and the sum of (viii) and (ix).