# T73S03 Session 44A Homework

## Knowledge & Skills Questions from the Mentor Guide

[1.54] State the form of the creep crack growth law in terms of C(t)

[1.55] State how to obtain estimates of the creep crack growth law, in the absence of such test data, in terms of the creep ductility or the rupture time.

[1.56] State the criterion for the da/dt-C* correlation to be valid, and define the dimensionless crack velocity. Identify the approach to be used to assess creep crack growth if the C* correlation is invalid.

[1.57] Describe the provisions within R5 V4/5 for taking account of enhanced crack growth rates prior to steady cyclic conditions being attained (in the case of significant cyclic loading).

[1.58] Describe the simplified means of accounting for the enhanced creep crack growth during redistribution when the overall assessment time exceeds $t_{red}$.

[1.59] Describe the two methods for combining fatigue and creep crack growth. Explain how creep crack growth is taken into account for cracks within the cyclic plastic zone.

[1.60] Discuss how the effects of prior creep damage may be taken into account in the assessments of fatigue and creep crack growth rates.

[1.61] State the procedure within R5 for assessing defects which have initiated in-service.

[1.69] State the combinations of materials data bounds that must be employed for creep strain rate and creep crack growth law parameters, for (a)ferritic materials, (b)austenitic materials.

## Numerical Question

A new circumferential butt weld has been made between pipe sections with negligible prior service creep or damage. The feature is to enter service in the as-welded condition. The parent and weld materials are 316H/316 and the operating temperature is 525°C. The inner and outer radii are 180mm and 220mm. Inspection failed to find any significant defects but you are required to assume the existence of a fully circumferential crack of a depth equal to the NDT tolerance of 3mm.

The internal pressure is 160 barg with atmospheric pressure outside. No stresses act other than pressure stresses and welding residual stresses. For the purposes of this exercise the hoop and axial pressure stresses should be treated as uniform membrane stresses, of a magnitude determined by equilibrium. (*Real assessments might be rather more careful of the details*).

It has been decided to assess the welding residual stresses as a membrane hoop stress and a wall-bending axial stress. The magnitude of the former is to be assessed as the mean weld 1% proof strength at operating temperature, i.e., $\sigma_{hm}^{res}$ = 340 MPa. The magnitude of the latter is to be assessed as the mean parent 1% proof strength at operating temperature, i.e., $\sigma_{ab}^{res} = 160$ MPa.

All the above stresses are to be interpreted as “elastic” stresses.

Plastic reference strain is to be estimated using $\varepsilon_{ref}^{P} = \left(\frac{\sigma_{ref}}{854}\right)^5$ (consistent with the weld 1% proof strength). Young’s modulus is 160 GPa.

Load cycling has been shown to be insignificant and fatigue crack growth has been shown to be negligible.

A membrane SIF solution which is sufficiently accurate over the crack depths of interest is,

$$\frac{K_m}{K_{m0}} = \frac{1}{(1 - a/t)^{0.75}} \qquad (t = R_o - R_i)$$

In terms of the load resultants, the reference stress solution to be employed is,

$$\sigma_{ref} = \sqrt{\frac{3}{4}\left(\frac{N_h}{t}\right)^2 + \left[\frac{2M_a}{(t-a)^2} + \sqrt{\left(\frac{2M_a}{(t-a)^2}\right)^2 + \left(0.5\frac{N_h}{t} - \frac{N_a}{t-a}\right)^2}\right]^2}$$

where $\sigma_{hm} = \frac{N_h}{t}$ is the total hoop membrane stress (primary plus secondary), $\sigma_{am} = \frac{N_a}{t}$ is the uncracked axial membrane stress (pressure) and $\sigma_{ab} = \frac{6M_a}{t^2}$ is the uncracked axial bending stress (residual). *NB: I am not suggesting that this reference stress solution, or the SIF solution, would be appropriate in real assessments. This is just an exercise!*

The factors which account for secondary load relaxation due to the crack itself are $\gamma_{hm} = 1$ and $\gamma_{ab} = 1 - a/t$. Considering times up to 100,000 hours…

- Calculate the crack depth against time using the methodology of Ainsworth, Dean & Budden and allowing for relaxation due to both creep and cracking.
- Plot the relaxing hoop membrane residual stress and axial bending residual stress (uncracked) against time.
- How close to the primary reference stress does the total reference stress get?
- Does the dimensionless crack velocity remain within the required limit?

The assessment is required to ignore any incubation period.

Assume mean RCC-MR creep deformation and the upper bound creep crack growth law, $\dot{a} = 0.221C(t)^{0.891}$ m/hour (which is likely to bound the approved combinations).

State if you are using strain hardening or time hardening (*you should really use strain hardening, but I don't mind for this exercise*).

Use $Z = 3$ and evaluate $n$ in the $C(t)$ formula from the value of $q$.

*For the purposes of this exercise you need not carry out the R6 assessment of crack stability, nor the creep rupture assessment of the ligament, which would be required in a complete assessment.*

*Hint: Use Neuber to find the initial uncracked elastic-plastic reference stress and corresponding elastic and plastic strains.*

*Hint: Remember that the plastic strain cannot reduce.*

*Hint: You could calculate the crack growth without evaluating the relaxed secondary loads (i.e., by dealing with the relaxing reference stress alone). However, because I have explicitly asked for the relaxed residual stresses you will need my Equs.(16a-d). Use these to find the relaxed load resultants from the relaxed reference stress – for both initial plastic relaxation and then creep relaxation.*