FULL THERMAL SIMULATION OF AN ARBITRARY, PLANE, AXISYMMETRIC RESIDUAL STRESS FIELD

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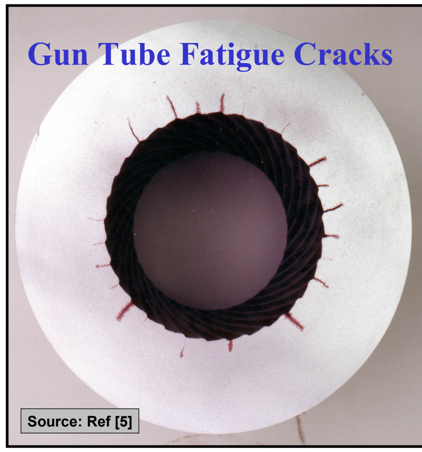
Cranfield UNIVERSITY

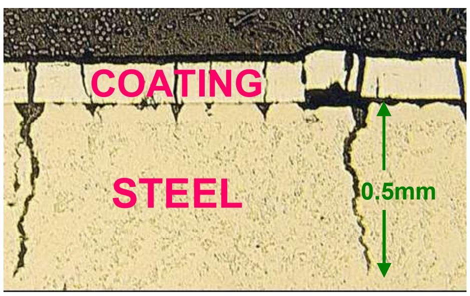
Gun Tube Fatigue Cracks



Source: Ref [5]

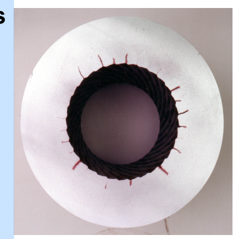
UK MoD & QINETIQ (UK) Test programs (Tony Andrews)

Cannon firing – Thermal Cracking 120 mm Tube after ~50 rounds



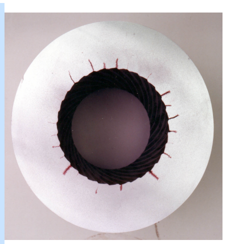
Thermal Damage, Cracking and Rapid Erosion of Cannon Bore , Underwood et al, GT2002

Simulation of Residual Stress to obtain Crack Tip Stress Intensity: OPTIONS



1. **Crack-Line Loading**
2. **Bueckner's Weight Function (Green's Function)**
3. **Equivalent Thermal Stress Field with Stress-free crack, FEA (Perl)**

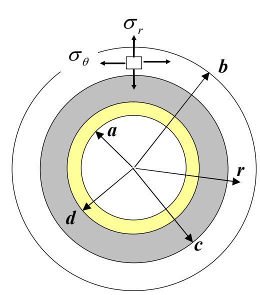
Simulation of Residual Stress to obtain Crack Tip Stress Intensity: OPTIONS



1. **Crack-Line Loading**
2. **Bueckner's Weight Function (Green's Function)**
3. **Equivalent Thermal Stress Field with Stress-free crack, FEA (Perl)**

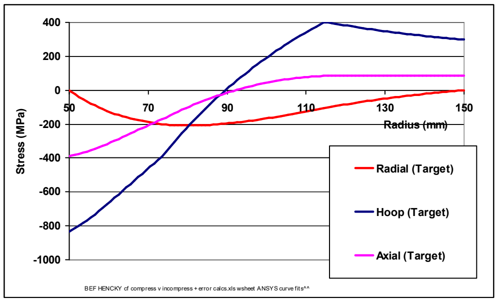
Axial Stresses are not Correctly Modeled

Tube Geometry and Zones



Geometry, general radius r, innner radius a, outer radius b, autofrettage yielding radius c, re-yielding radius d. Axial (z) direction is normal to the plane shown.

Hydaulic Autofrettage: Residual Stresses



Numerical Stress Profile, Hydraulic Autofrettage, A723 Steel, Y = 1000 MPa
(Basis of ASME Code Division 3, Section VIII [Bauschinger effect])

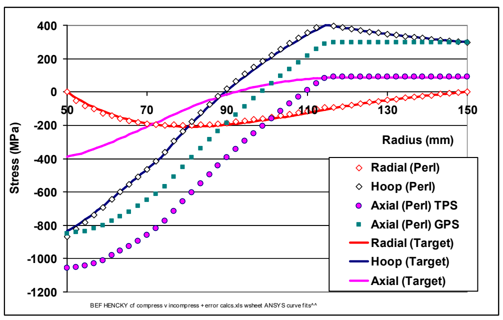
Perl's Inverse Formulation to Obtain Temperature Profile

$$T_P(r_i) = \frac{(1-\nu)}{E\alpha_0}[\sigma_\theta(a) - \sigma_r(r_i) - \sigma_\theta(r_i)]$$

1. ***r_i is an initial location very close to the bore.***
2. ***With $T_P(a)$ set to zero 'outward' steps determine entire temperature profile from a to b***
3. ***This procedure reproduces hoop and radial stresses but cannot define axial stresses.***

r_i

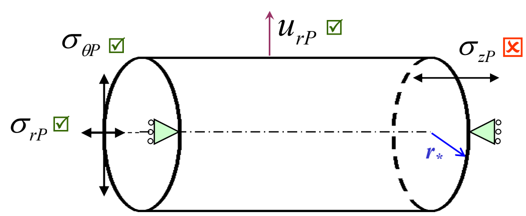
Hydraulic Autofrettage: Perl's Simulation



Numerical Stress Profile, Hydraulic Autofrettage, A723 Steel, Y = 1000 MPa

Plane Strain Thin Tube Extracted from Thick Cylinder Containing Perl's Thermal Stresses

$$\sigma_{zP}(r) = \nu[\sigma_{rP}(r) + \sigma_{\theta P}(r)] + E\alpha_0 T_P(r)$$



Axial Stress: re-formulation

At radius r_*.................

$$\sigma_{zP}(r_*) = \nu[\sigma_{rP}(r_*) + \sigma_{\theta P}(r_*)] + E\alpha_0 T_P(r_*)$$

Requires a correction to $\sigma_{zP}(r_*)$, designated $\sigma_{zC}(r_*)$, where:

$$\sigma_{zC}(r_*) = \sigma_{z\_\text{Target}}(r_*) - \sigma_{zP}(r_*)$$

Introduce orthotropic CTEs, $\alpha_r(r_*), \alpha_\theta(r_*), \alpha_z(r_*)$

where $\alpha_r(r_*) = \alpha_\theta(r_*)$

Derivation of Orthotropic Coefficients

Vary $\alpha_z(r_*)$ from the original $\alpha_0(r_*)$ by $\alpha_{zC}(r_*)$, where:

$$\alpha_{zC}(r_*) = \sigma_{zC}(r_*)/(ET_P(r_*))$$

total orthotropic axial CTE, $\alpha_{zTotal}(r_*)$, becomes:

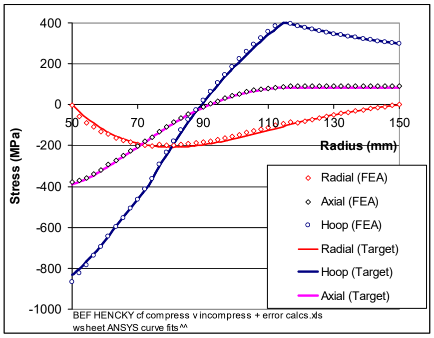
$$\alpha_{zTotal}(r_*) = \alpha_o(r_*) - \sigma_{zC}(r_*)/(ET_P(r_*))$$

To mimic radial displacement orthotropic radial CTE, $\alpha_{rTotal}(r_*)$ becomes:

$$\alpha_{rTotal}(r_*) = \alpha_o(r_*) + \nu\sigma_{zC}(r_*)/(ET_P(r_*))$$

Replace r_* with r >> General Relationship

Hydraulic Autofrettage: Full Thermal Simulation



Hydraulic Autofrettage: Temp &Thermal Strain

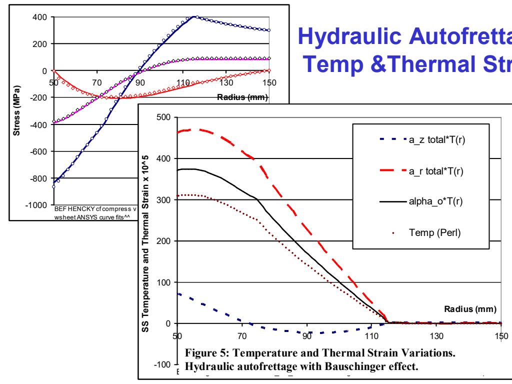


Figure 5: Temperature and Thermal Strain Variations. Hydraulic autofrettage with Bauschinger effect.

Swage Autofrettage: Full Thermal Simulation

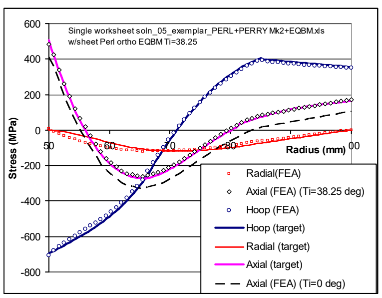
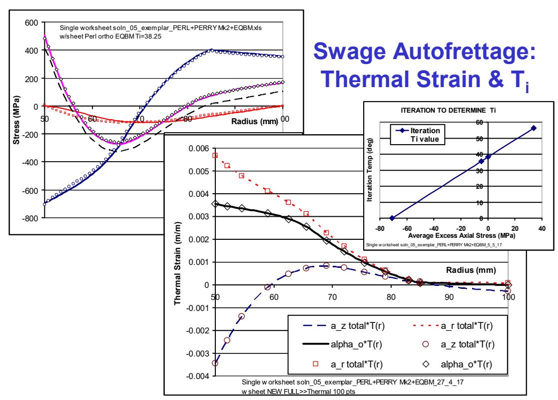
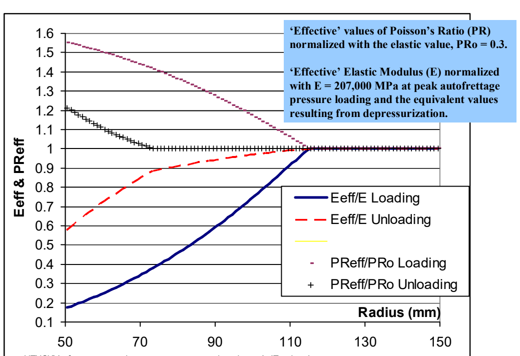


Figure 6: Numerical Stress Profile, Swage Autofrettage, Perry & Perl FD Solution

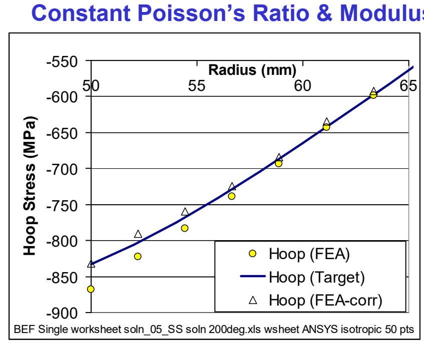
Swage Autofrettage: Thermal Strain & T_i



Near-Bore: Poisson's Ratio (PR) & Modulus (E)



Hydraulic Autofrettage: Near-Bore Correction for Constant Poisson's Ratio & Modulus



Conclusions & Applications

1. Full thermal simulation can be achieved via orthotropic CTEs,
2. Near bore effects exist, causing errors of 5 to 7%,
3. Near bore effects can be eliminated numerically, reducing error to 0.5%,
4. Method will permit:

    a. Determination of Stress Intensity for arbitrarily-orientated cracks,

    b. Modelling subsequent non- axisymmetric loading of autofrettaged tubes.

THE END