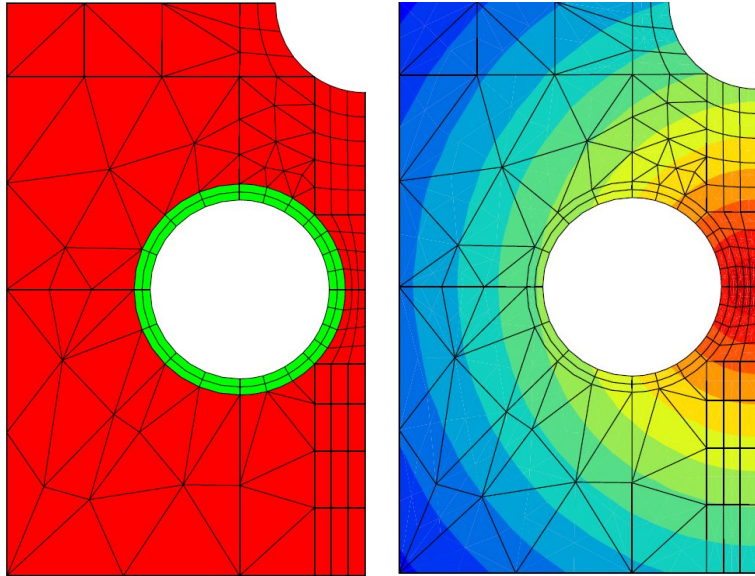


Thermomechanical fatigue on a cylinder head



Cylinder heads are critical parts in car engine, specially in the new engine generations, where temperature increases to improve the efficiency of the combustion. Car manufacturers use to manipulate large 3D models in order to optimize the geometry of the components. They have to deal with complex material models, including plasticity and time effect. The purpose of the present text is to investigate the influence of the material behaviour on the life prediction results. As shown in the previous figure, the system is limited to a 2D geometrical model. Two materials are presents, a cast aluminium alloy in the cylinder head itself, and high resistance steel for the valve seat. Both left and right hand edges remain vertical, figuring the symmetries present in the full component. The temperature field is variable in time and space. The figure shows a typical map at maximum temperature.

1 Plastic and viscoplastic model simulation

The first step of the study consists in a comparison of the responses of the constitutive equations by using a simple driver allowing the user to apply prescribed loading on a material element. Monotonic loading is considered, together with a relaxation test. For a good representation of cyclic loadings, non linear kinematic hardening is introduced. The size of the elastic domain is constant. Time independent plasticity is compared to viscoplasticity. All the material parameters are temperature dependent. These parameters can be modified, to check their influence. A suite of commands is available for this purpose.

Go to directory `shell`

Edit the material files `alu_plas.mat` and `alu_visco.mat` with the command :

```
./edit_mat_files
```

Set the simulation temperature with the command :

```
./set_temp_x
```

Edit the simulation input files `plas.inp` and `alu_visco.inp` with the command :

```
./edit_simu_files
```

Run the simulations with the command :

```
./run_sim_x
```

Draw the stress–strain and relaxation curves with the command :

```
./draw_sim_x
```

2 Damage models

The main objective of this project is to observe the effect of damage during a cyclic thermal loading. Here, the damage of the material comes from two main sources : fatigue and creep. The part due to fatigue is described by a model developed at the ONERA while the creep damage is described by the model of Kachanov.

2.1 Fatigue damage model (ONERA)

$$N_F = \frac{\langle \sigma_u - \sigma_{max} \rangle}{a(\beta + 1) \langle \bar{\sigma} - \sigma'_l(\sigma_H) \rangle} \left[\frac{\bar{\sigma}}{M(\sigma_H)} \right]^\beta$$

with:

- σ_{max} max stress value (max principal stress in 3D)
- $\bar{\sigma} = \frac{\Delta\sigma}{2}$ stress amplitude
- σ_H mean trace of σ
- σ_u ultimate stress: if $\sigma \geq \sigma_u$ then $N_F = 0$
- σ_l fatigue limit: if $\sigma \leq \sigma_l$ then $N_F = \infty$

mean stress effect:

- $\sigma'_l(\sigma_H) = \sigma_l(1 - b_1 * \sigma_H)$
- $M(\sigma_H) = M(1 - b_2 * \sigma_H)$

For anisothermal loadings the stress history is normed by $i\sigma_u(T)$

2.2 Creep damage model (Kachanov)

$$dD_C = \left(\frac{\bar{\sigma}}{A} \right)^r \frac{1}{(1 - D_C)^k} dt$$

with:

$$\bar{\sigma} = \alpha_0 \sigma_p + \alpha_1 \sigma_H + (1 - \alpha_0 - \alpha_1) J(\sigma)$$

and:

- $J(\sigma)$ mises invariant of σ
- σ_p first principal stress
- σ_H mean trace of σ
- $\alpha_0, \alpha_1, r, k, A$ material parameters that depend on temperature

Integration between 0 et 1 yields the critical time t_C for creep initiation:

$$t_C = \frac{1}{k+1} \left(\frac{\sigma}{A} \right)^{-r}$$

2.3 Non-linear cumulation of creep/fatigue damage

The combination of the fatigue and creep contributions is given by the following relations.

For each cycle damage goes from D_i to D_f :

- damage increases from D_i to D_c due to creep

$$C = (1 - D_i)^{k+1} - (1 - D_c)^{k+1}$$

- damage increases from D_c to D_f due to fatigue

$$F = \left[1 - (1 - D_f)^{\beta+1} \right]^{1-\alpha} - \left[1 - (1 - D_c)^{\beta+1} \right]^{1-\alpha}$$

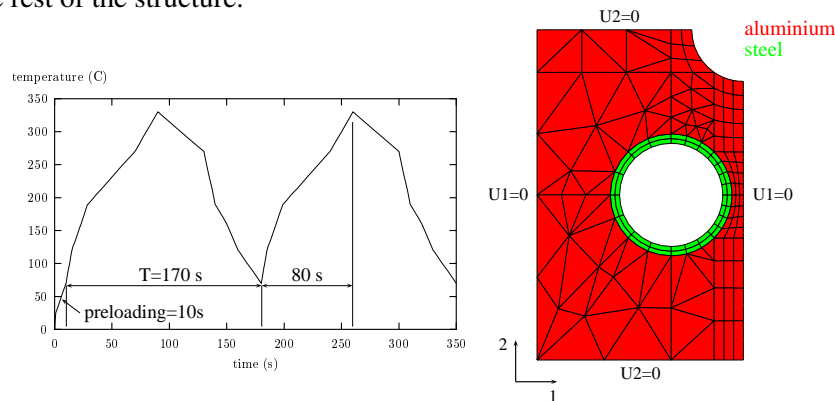
where:

- C increase of damage on one cycle due to pure creep
- F increase of damage on one cycle due to pure fatigue
- α depends on the loading:

$$\alpha = 1 - a \frac{\bar{\sigma} - \sigma'_l}{\sigma_u - \sigma_{max}}$$

3 FE computations

The model is now ready to perform a simulation of a cyclic thermal loading on the structure. The thermal loading is shown on the following curve. The boundary conditions imposed on the structure are also displayed: it is assumed that the normal displacements are blocked due to the presence of the rest of the structure.



The next two commands are designed to create the thermal field and to check the finite element mesh.

Go to directory shell

Build the thermal loading file with the command :

```
./make_t_file
```

View the mesh with the command :

```
./view_mesh
```

3.1 Effect of viscoplasticity

The first step of the FE Analysis consists in highlighting the effect of the viscosity. Follow the next instructions and conclude on the difference between plasticity and viscoplasticity.

Edit the input file `culasse_plas.inp` and the post calculation file `last_cycle_plas.inp` :

```
./edit_inp_plas
```

Run the FE simulation and the post calculation of life assesment :

```
./exe_plas_x
```

```
./exe_post_plas_x
```

Observe the results of the FE simulation :

```
./view_results_plas
```

Follow the same procedure, replacing `plas` by `visco` for each command. Look at the critical points and draw the curves corresponding to these points:

```
./critical_locations
```

```
./draw_x
```

At the end of this section, the report should include a list of stress and plastic strain contour maps, explaining how the system operates during thermomechanical cycles, and the location of the critical zones. The stress-strain loops should be plotted in these areas.

3.2 Effect of a temperature dwell

Hold time at high temperature will influence the stress redistribution (lower stresses) but will increase creep damage. The competition between the two mechanisms is investigated in this section.

Set the hold time value with the command :

```
./enter_hold_time_value
```

Run the FE computations with hold time by following the same procedure as previously, but with the `plas_tm` and `visco_tm` problems.

Look at the critical points and draw the curves corresponding to these points:

```
./critical_locations_tm
```

```
./draw_tm_x
```

3.3 Results summary

Compare the evolution of the stresses and strains in all the computations. Compare also the results of the damage model. Sum up the results by filling the following table. Try different hold time values and compare at the critical locations *gptemperature*, *epcum*, *DNsig*, *Nsigmises* ...

	Plasticity		Viscoplasticity	
no hold time				
NF	59060	e25/p4	140600	e25/p2
NC	1.789 10 ⁷	e12/p4	2.37 10 ⁷	e12/p4
NR_NLC	44000	e37/p2	125100	e12/p4
hold time = 50s				
NF	67400	e25/p4	152500	e25/p2
NC	3.33 10 ⁶	e12/p4	5.051 10 ⁶	e12/p4
NR_NLC	37480	e37/p2	104400	e12/p4
hold time = 500s				
			...	