Cyclic plasticity's models for thermo-mechanical applications. Case of a copper mold for continuous casting

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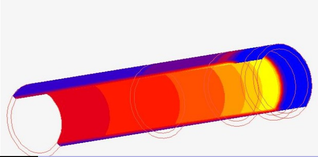


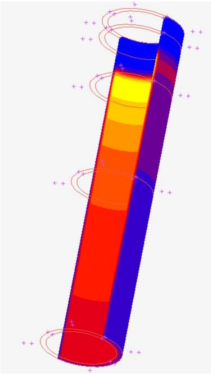
Summary

- Introduction
  - Presentation of the case studied
  - Cyclic behavior of materials
- Case study
  - Thermo-mechanical application of the mold through:
    - Combined model
    - Accelerated model
    - Stabilized model
    - Linear kinematic model
- Fatigue life assessment
- Conclusions

Introduction

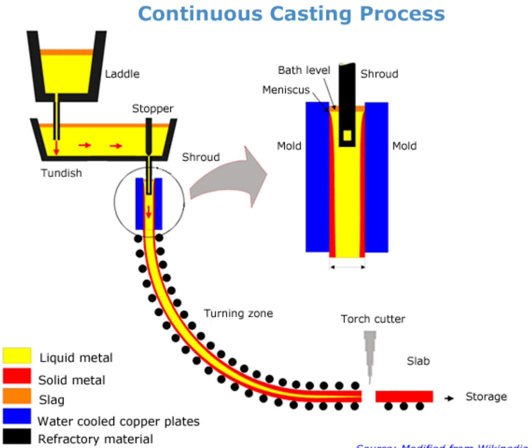
Several mechanical components work undergoing high stresses, cyclic loading, high temperature etc. The procedure adopted is

- **Analyze results** obtained from different material model susing Marc Mentat to analyze thermal-structural behavior.
- **Assess service life** of a copper-silver mold.
- **Find the most suitable model** in terms of solution's reliability and time employed;



Case study: the copper-silver mold

Copper-silver mold is a **key component for the continuous casting**.



Source: Modified from Wikipedia

Material behavior

Main concepts:

- The goal is to **find appropriate material models** which are able to simulate behavior very similarly with experimental data.

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- **Different materials** under cyclic loading **behave in different ways**;
- **So** far, many researchers aimed to describe cyclic behavior for different materials, thereby developing **several constitutive equations**;

Main hardening models

The most important are able to capture some physical features through description of the yield surface.

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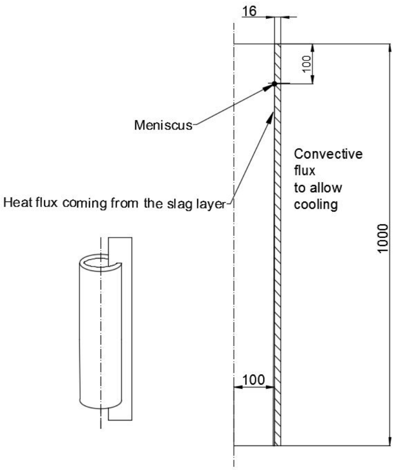
- Combined ⇒ Isotropic + Kinematic

Model definition: Geometry [Galdiz,2014] and mesh



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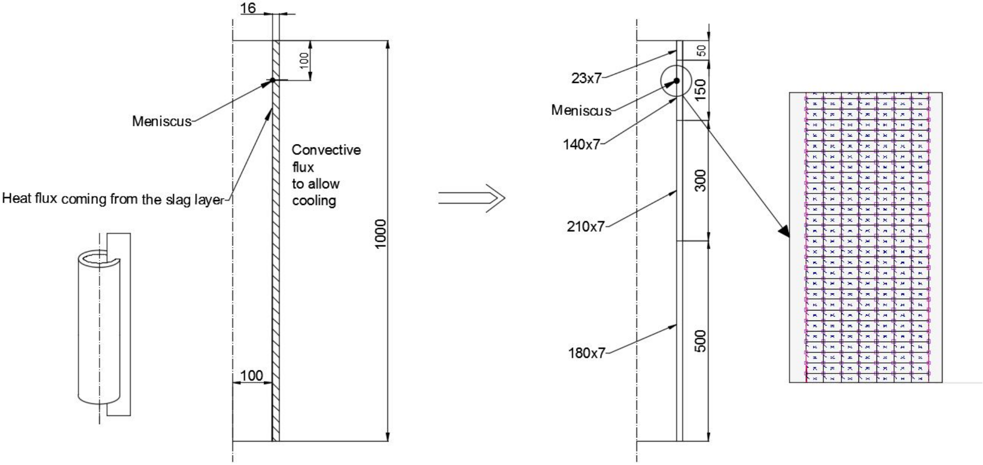
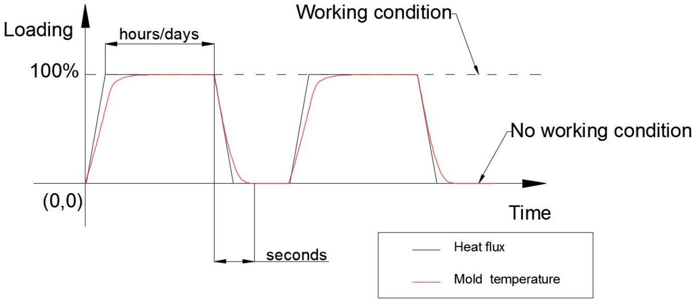


Modeling

- Material properties [Novak, 2013], are adopted for a combined model;

Temp. [°C]	E[GPa]	σ_{y0}[MPa]	C [MPa]	γ[MPa]	R_∞[MPa]	b
20	119	130	42 250	617	−75.7	2.35
250	104	111	45 340	820	−80.2	3.89
300	103	110	40 080	832	−76.7	5.29

- Boundary conditions [Galdiz,2014] are required to simulate the working conditions;



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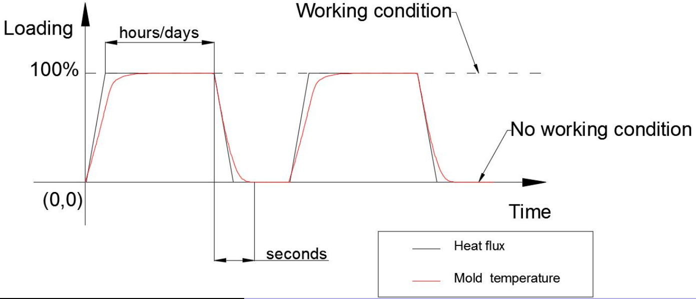
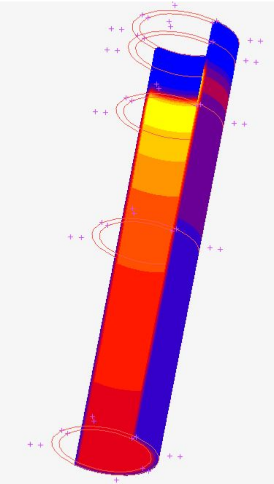


Temperature field



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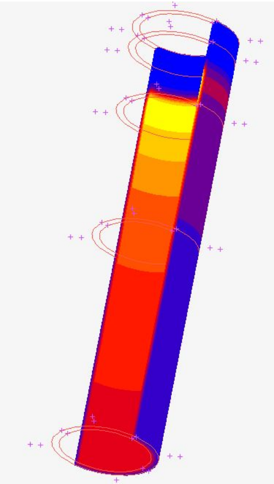
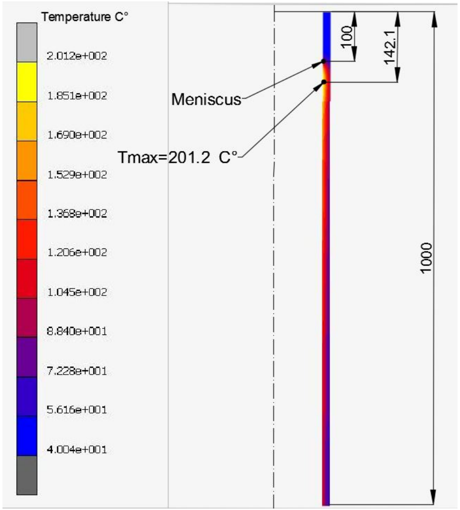
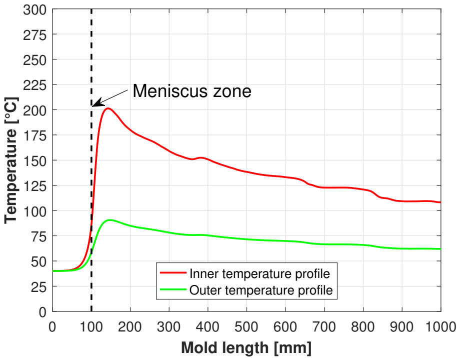
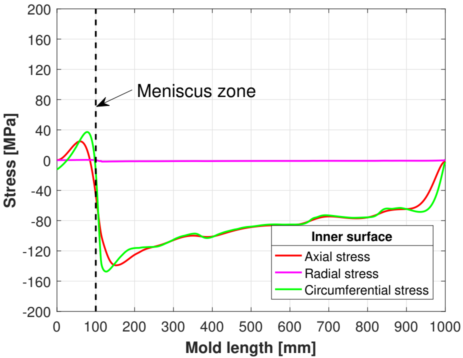




Temperatures and stresses distribution

- Temperatures profile; Stress profiles in the inner surface;





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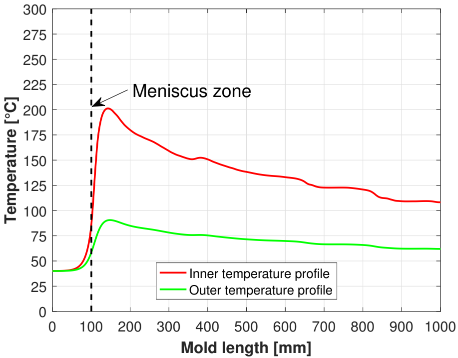
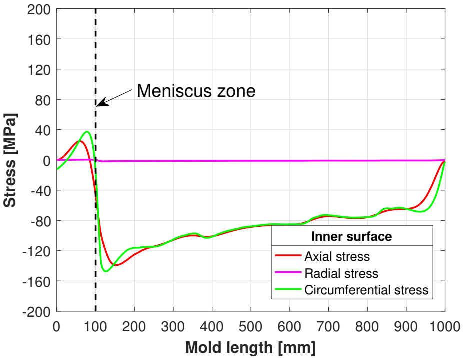
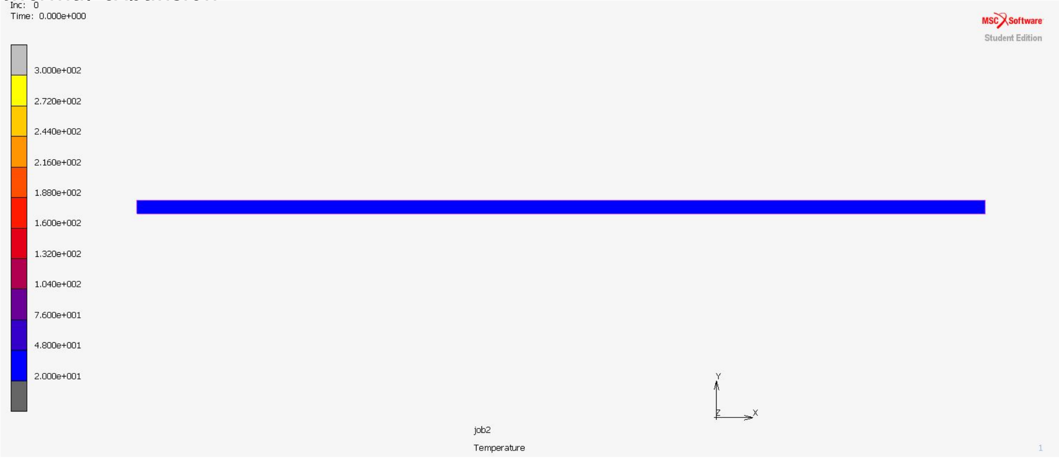




- The critic point is where the maximum temperature occurs [Mahapatra,1991];

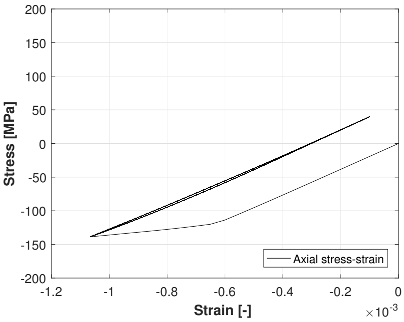
Thermo-structural behavior

The profile plotted supplies temperature field, with the deformations determined by thermal expansion.



Stress-strain curves

After the first cycle, in each direction the stress is not able to overcome the actual yield stress arisen.



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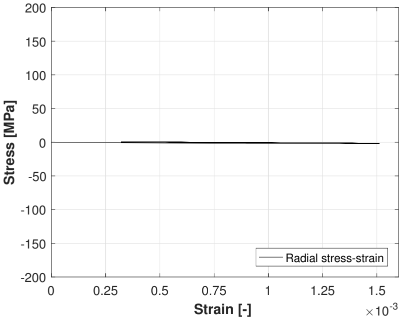

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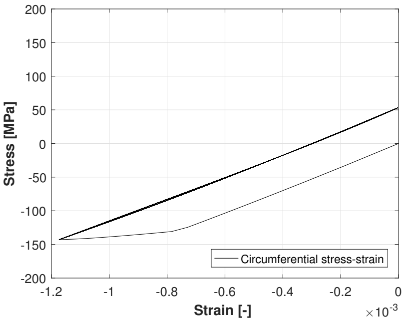

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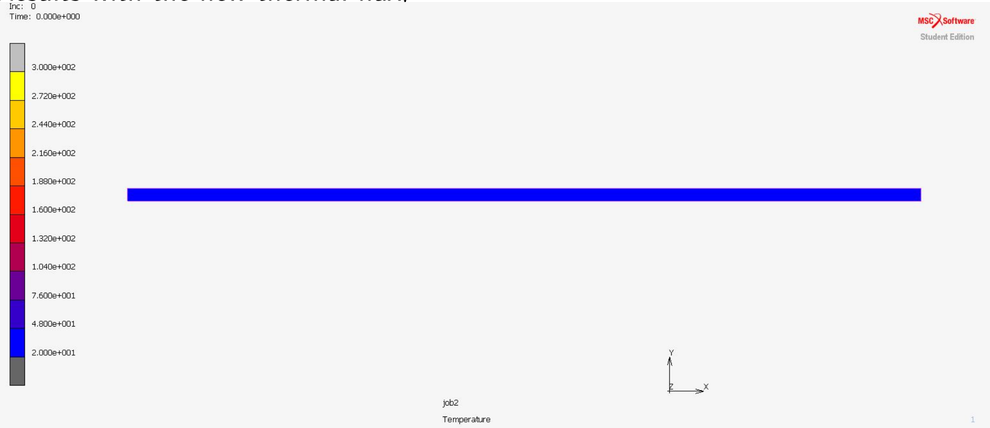
Thermo-structural behavior

- Results with the new thermal flux;



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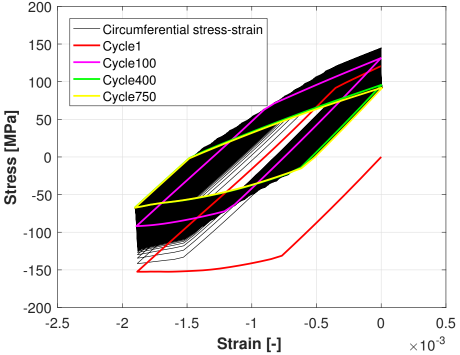
  - Stabilized.
  - Linear kinematic or Prager's model;
- In order to determine the number of cycles to reach stabilization, an empiric formula has been used [Lemaitre,Chaboche,1994]: $2bN\Delta\varepsilon_{pl} \approx 5$
- In order to determine uniquely stabilized conditions it is used this own criterion.
  $((\Delta\varepsilon_{pl,n+10} - \Delta\varepsilon_{pl,n})/\Delta\varepsilon_{pl,n})100 < 0.35$

Results with the combined model

Cyclic behavior in circumferential direction: stress strain curve and plastic strain range behavior. This model supplies the best results with experimental data.



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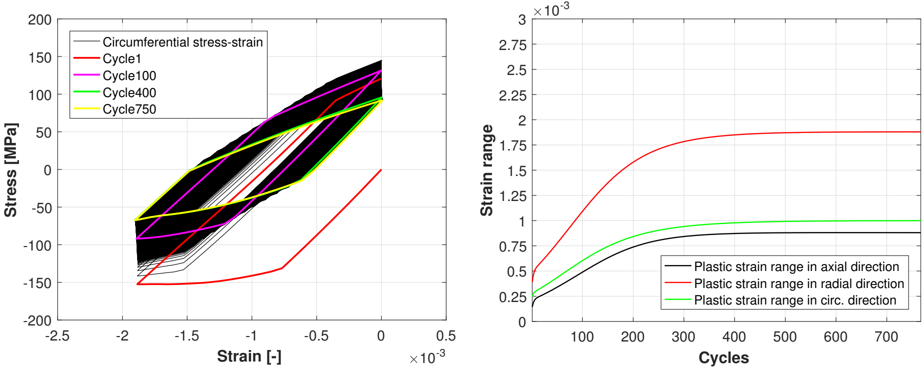
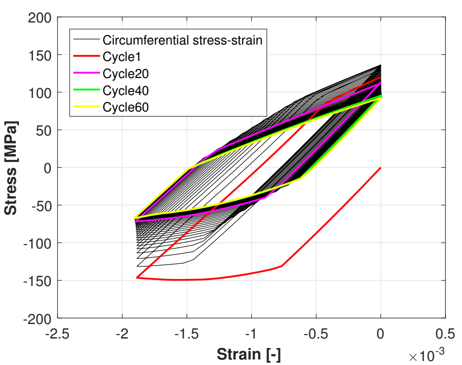
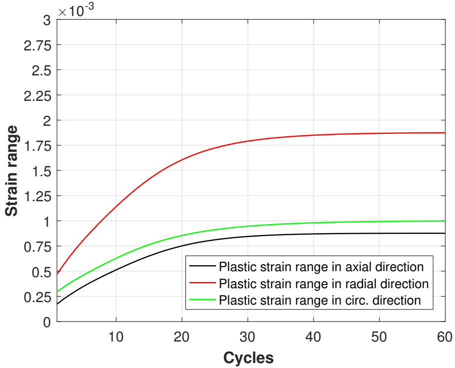


Here 750 cycles are plotted, the solver took $36\,715s \approx$ **10 h** ; stabilization is reached after 349 cycles.

Accelerated model with $b = 10b_i$

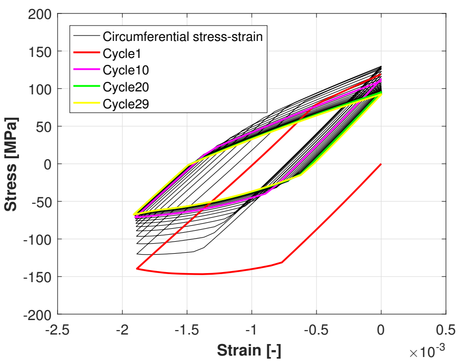
Such model allows a great reduction of the number of cycle to obtain stabilization.

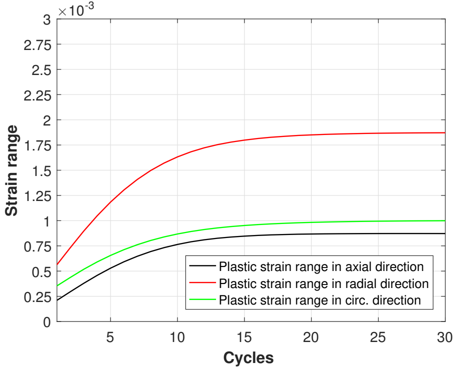




Here 60 cycles are plotted, the solver took $2\,266$ s (comparing with the first case time reduction is 93.8%); stabilization is reached after 58 cycles.

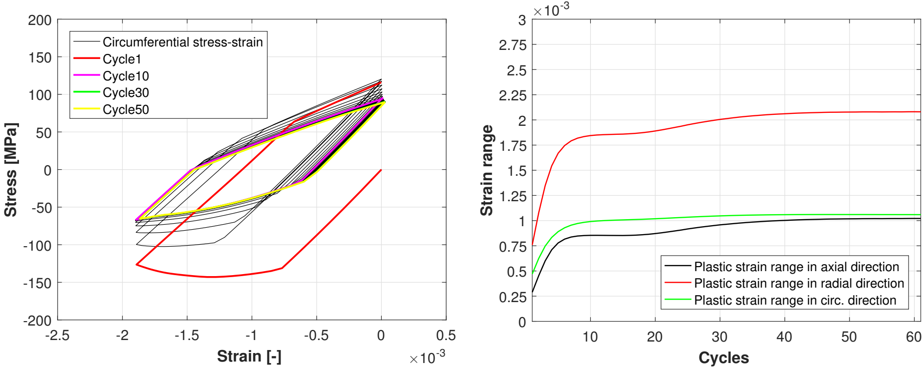
Accelerated model with $b = 20b_i$





Here 30 cycles are plotted, the solver took $1\,136$ s(comparing with the first case time reduction is 96.9%); stabilization is reached after 28 cycles.

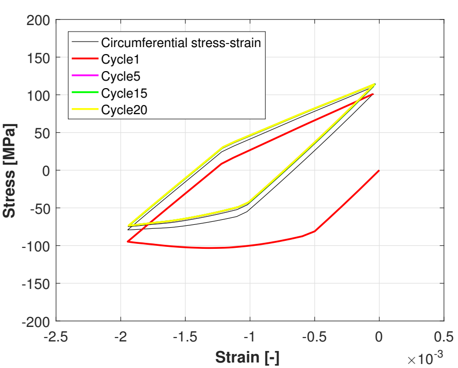
Accelerated model with $b = 40b_i$

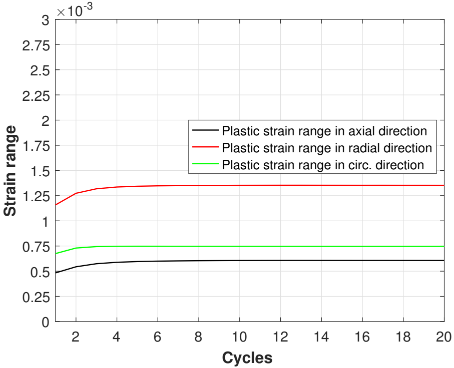


Here 60 cycles are plotted, the solver took $2\,560$ s(comparing with the first case time reduction is 93.0%); stabilization is reached after 51 cycles.

Stabilized model

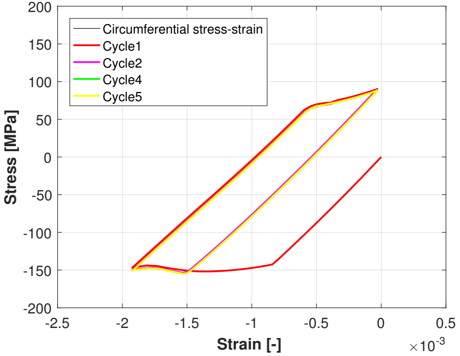
It exploits material data from stabilized conditions, it is a non linear kinematic model.

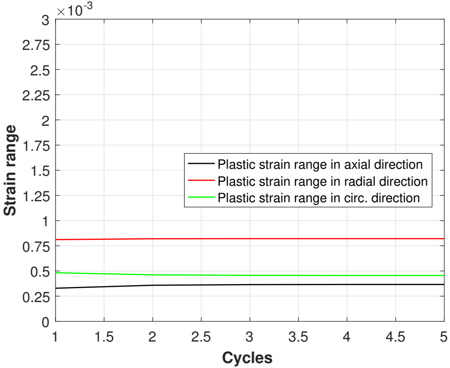




Here 20 cycles are plotted, the solver took 534 s(comparing with the first case time reduction is 98.5%); stabilization is reached after 11 cycles.

Linear kinematic model



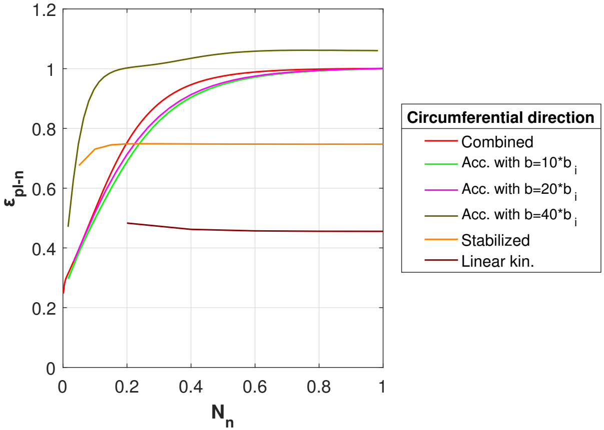


Here 5 cycles are plotted, the solver took $1\,002$ s(comparing with the first case time reduction is 97.3%); stabilization is reached after 3 cycles.

Comparison of plastic strain range

Normalizing the number of cycles and the plastic strain range, a comparison can be done.

- Considering the i^{th} model
  It has $N_n^i = \frac{N^i}{N_{stab}^i}$
  and $\varepsilon_{pl-n} = \frac{\Delta\varepsilon_{pl}^i}{\Delta\varepsilon_{pl,750,comb.model}}$



Cycles needed to reach stabilization

Now these steps are followed:

- **Number of cycles to obtain the stabilization** are determined;
- It has been listed the **time employed by the solver**;

Material model	Cycles computed	Time [s]	Cycles to stab.	Time to reach stabilization [s]	% Time saved
Combined	750	36 715	349	17 085	–
Acc. $b = 10 * b_i$	60	2 266	58	2 577	84.9
Acc. $b = 20 * b_i$	30	1 136	28	1060	93.8
Acc. $b = 40 * b_i$	60	2 560	51	2 176	87.3
Stabilized	20	534	11	294	98.2
Linear kin.	5	1 002	3	601	96.5

Fatigue life assessment

Now, fatigue life assessment can be carried out

- Evaluation of equivalent stain range [Manson, 2009] $\rightarrow \Delta\varepsilon_{eq}$.

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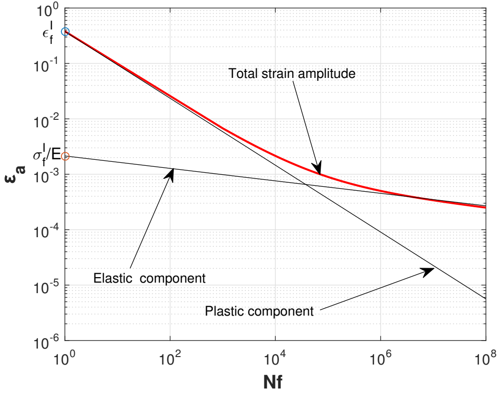
- N_f: Number of cycles to failure;



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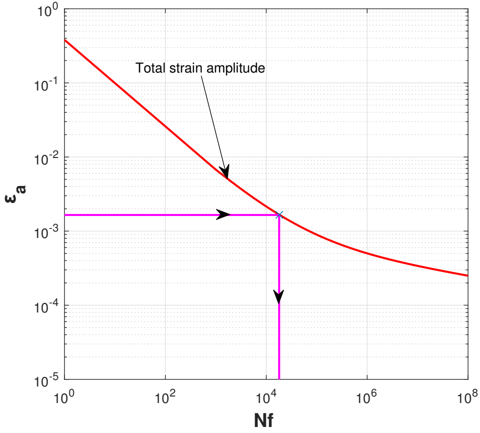

Fatigue life assessment

Material model	$\Delta\varepsilon_{eq}$ $*10^{-3}$	Life assessment $[Cycles]$	$\Delta\varepsilon_{rl}$ $[\%]$	% Time saved
Combined	3.16	20 461	–	–
Acc. with $b = 10 * b_i$	3.16	20 571	+0.5	84.9
Acc. with $b = 20 * b_i$	**3.15**	**20 631**	**+0.8**	**93.8**
Acc. with $b = 40 * b_i$	3.31	18 261	−10.8	87.3
Stabilized	2.98	23 791	+16.3	98.2
Linear kinematic	2.77	28 711	+40.3	96.5

Conclusions

Finally, for this study it can states that:

- Stabilized model and linear kinematic model allow a huge time saving but they don't lead to reliable results.
- Accelerated models represent a great solutions but the speed of stabilization have to be set opportunely.
- For further design purposes the accelerated model with $b = 20b_i$ represents a great solution.

THANK YOU FOR YOUR ATTENTION !

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