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# Automatic correction of the time step in implicit simulations of thermomechanical problems

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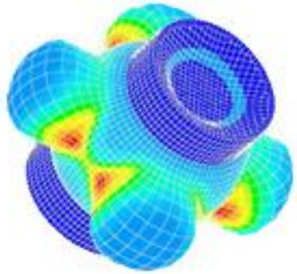

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# OUTLINE

- Introduction
- Thermomechanical coupling
- The in-house DD3IMP solver
- Classical algorithms
- Proposed algorithm
- Numerical examples
- Conclusions

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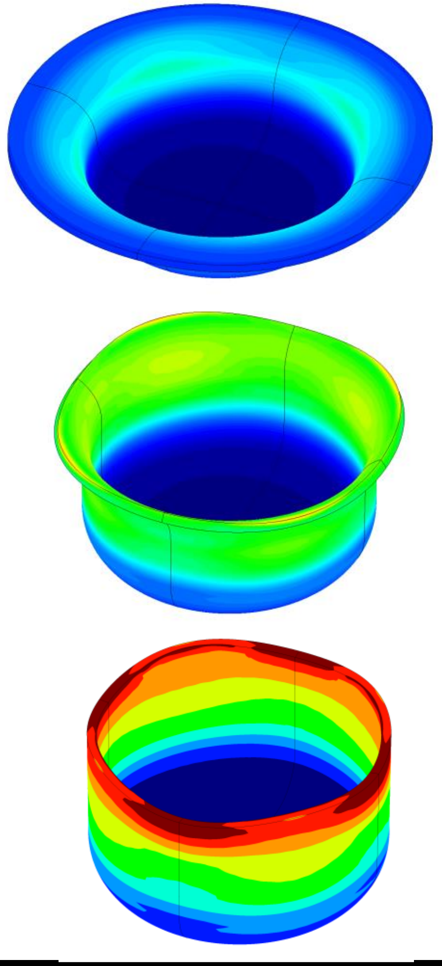
# INTRODUCTION

- The numerical modelling of thermomechanical systems is of high practical importance in many industrial applications.
- In fact, the prediction of temperature and stress fields is a key factor for various manufacturing processes, e.g. in the warm sheet metal forming.
- The development and implementation of numerical models to deal with thermomechanical problems is a challenge, since the interdependence between the thermal and the mechanical fields requires an efficient coupling strategy.



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# THERMOMECHANICAL COUPLING

The treatment of thermomechanical problems through the finite element method can be carried out using two coupling strategies:

**Monolithic strategy**

- Single system of equations
- Unconditional stability

**Staggered strategy**

- Two system of equations
- Requires a strategy for the exchange of information between the two systems
- Allow to reuse software already developed

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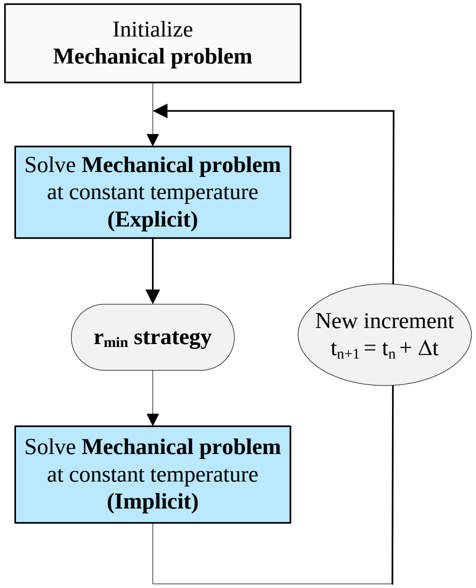
# THE IN-HOUSE DD3IMP SOLVER

**Main characteristics:**

- Elastoplastic formulation
- Update lagrangian scheme
- Hypoelastic law for the material behaviour description
- Fully implicit algorithms with Newton-Raphson method




Extended to incorporate, heat conduction and thermomechanical effects, such as heat generation by plastic deformation, thermal expansion and thermal softening

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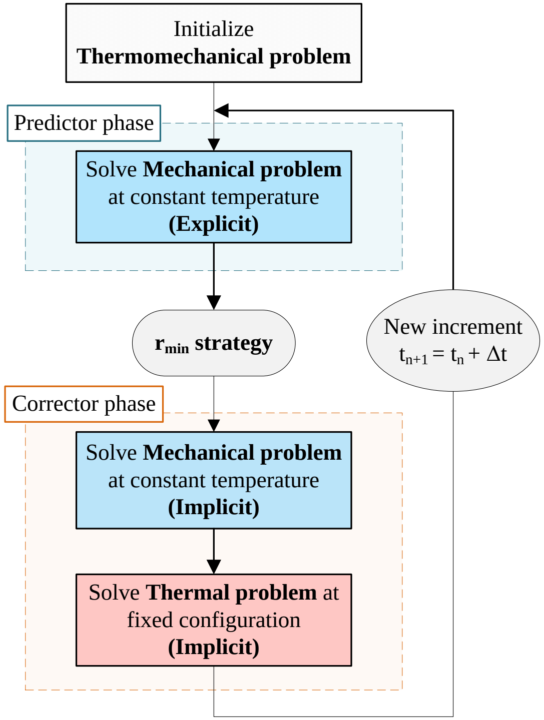
# CLASSICAL ALGORITHMS




## Explicit algorithm - MMT

- Developed to reach a low computational cost
- Comprises the interchange of information between the two fields only once at each increment.
- Since the mechanical problem is solved using the temperature of the previous increment, there is always a delay between the two problems.

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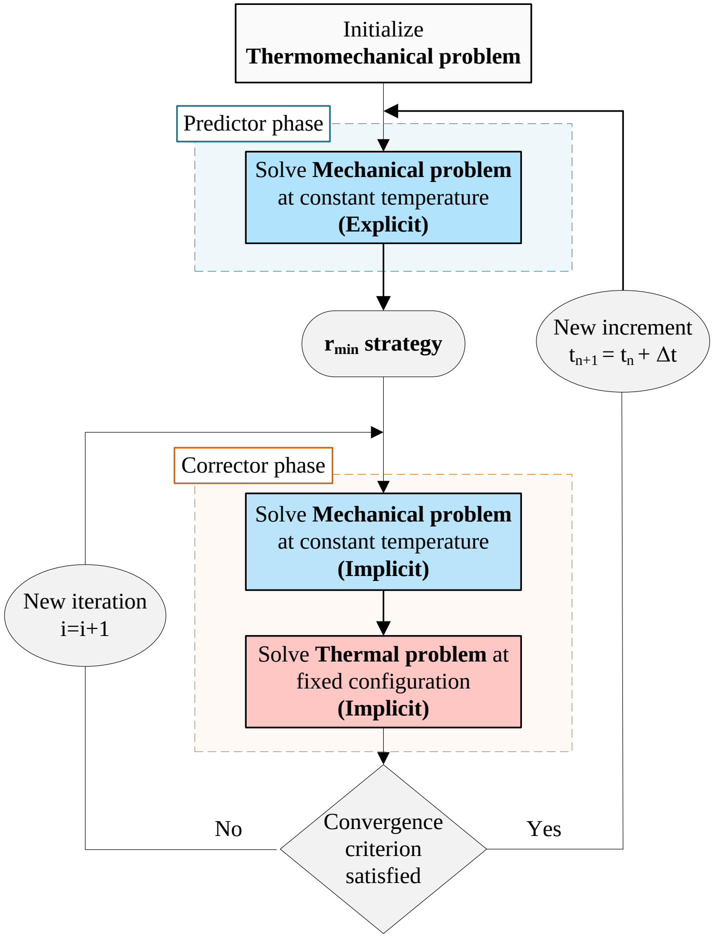
# CLASSICAL ALGORITHMS




## Iterative algorithm - MMIT

- Developed to reach higher accuracy on the results.
- Comprises the interchange of information between the two fields through an iterative procedure.
- Fully converged solution.
- Higher computational cost.

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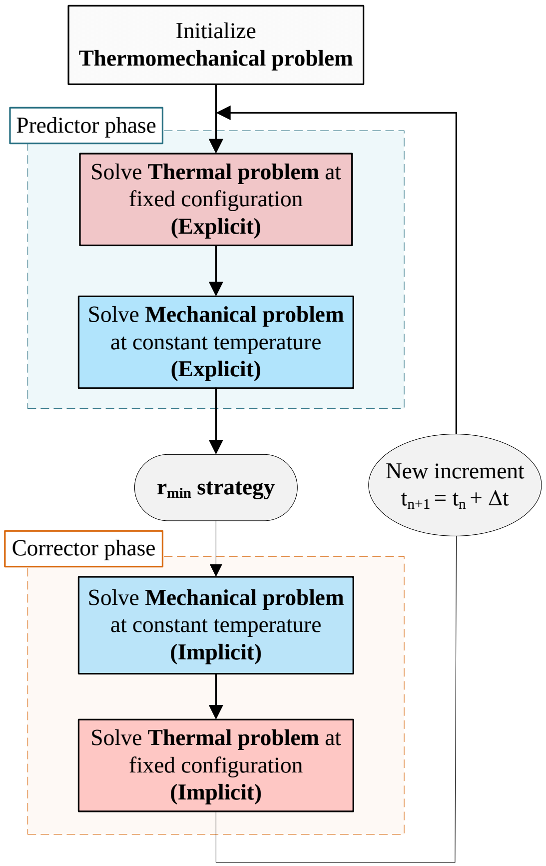
# PROPOSED ALGORITHM




## Proposed algorithm - TMMT

- Developed to reach a better compromise between computational cost and accuracy of the results.
- Two distinct phases: prediction and correction
  - **Prediction phase:** Explicit method for the mechanical problem and afterwards for the thermal problem.
  - R-min strategy
  - **Correction phase:** Implicit method for the mechanical problem and afterwards for the thermal problem.

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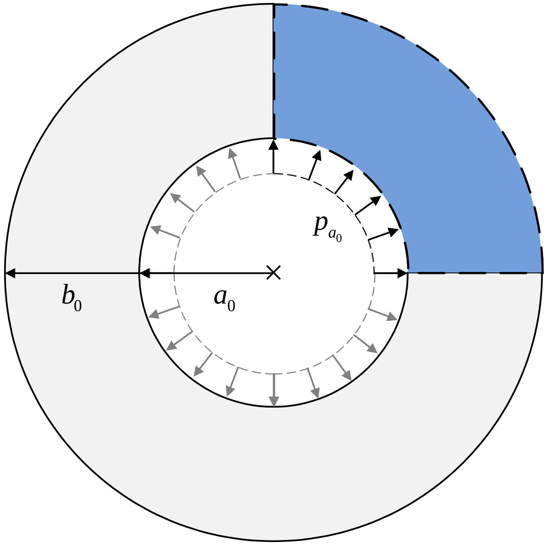
# NUMERICAL EXAMPLES

## Expansion of a thick-walled cylinder

(adapted from Simo and Miehe (1992))

**Numerical example conditions:**

- A thick walled cylinder infinite long, along the axial direction.
- It is subjected to a internal pressure (replaced by a radial displacement).
- The cylinder is assumed adiabatic (no heat exchanges with the environment).
- The only source of heat in this case is the heat generated by plastic deformation



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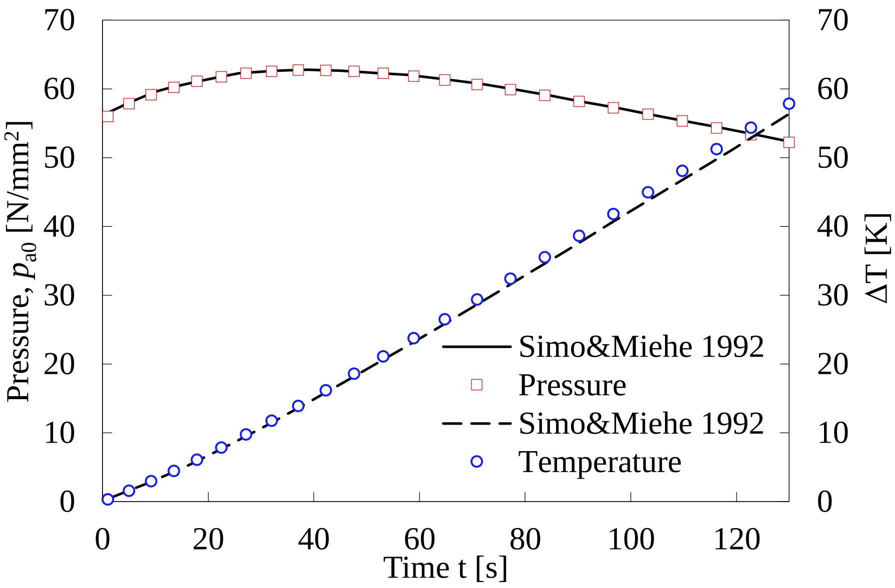
# NUMERICAL EXAMPLES

**Results anslysis:**

- The temperature increases during the loading, due to the heat generated by plastic deformation.
- The numerical results are in very good agreement with the results obtained by Simo and Miehe (1992).




Relative temperature evolution and internal pressure evolution.

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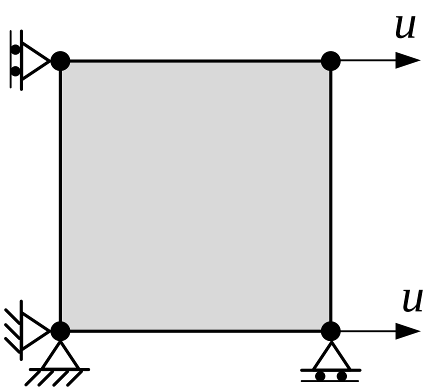
# NUMERICAL EXAMPLES

## Single element tensile test – $r_{min}$ strategy activated/deactivated

**Numerical example conditions:**

- Single finite element [1x1x1 mm$^3$].
- It is subjected to a tensile stress state, by imposing a displacement of $u = 2$ mm, at constant velocity $v = 1$ mm/s.
- The element is assumed adiabatic (no heat exchanges with the environment).
- The only source of heat in this case is the heat generated by plastic deformation.

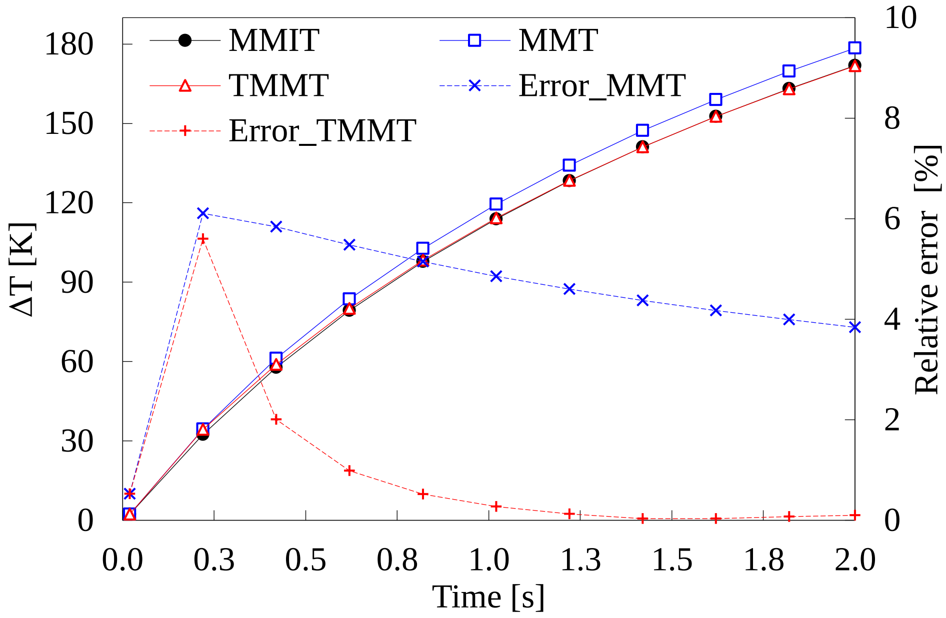


# NUMERICAL EXAMPLES

## $r_{min}$ strategy deactivated

**Results analysis:**

- The proposed algorithm (TMMT) uses the information of the last increment to determine the temperature field in the Prediction Phase.
- After the second increment, the error is significantly reduced for the TMMT algorithm.




**Note:** The relative error was evaluated considering the iterative solution as reference (MMIT), since this is the most accurate.

Relative temperature evolution obtained with the MMIT, MMT and TMMT algorithms, including relative error.

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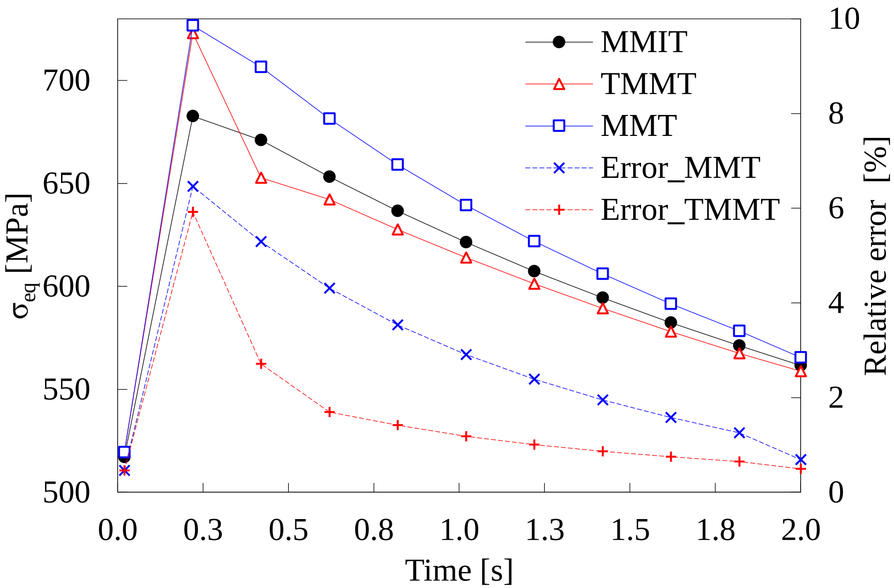
# NUMERICAL EXAMPLES

## $r_{min}$ strategy deactivated

**Results analysis:**

- The equivalent tensile stress decreases with the temperature increase, consequence of the softening effect.
- The equivalent stress is underestimated for the TMMT algorithm, but the error is always lower for it.




Equivalent (von Mises) stress evolution obtained with the MMIT, MMT and TMMT algorithms, including relative error.

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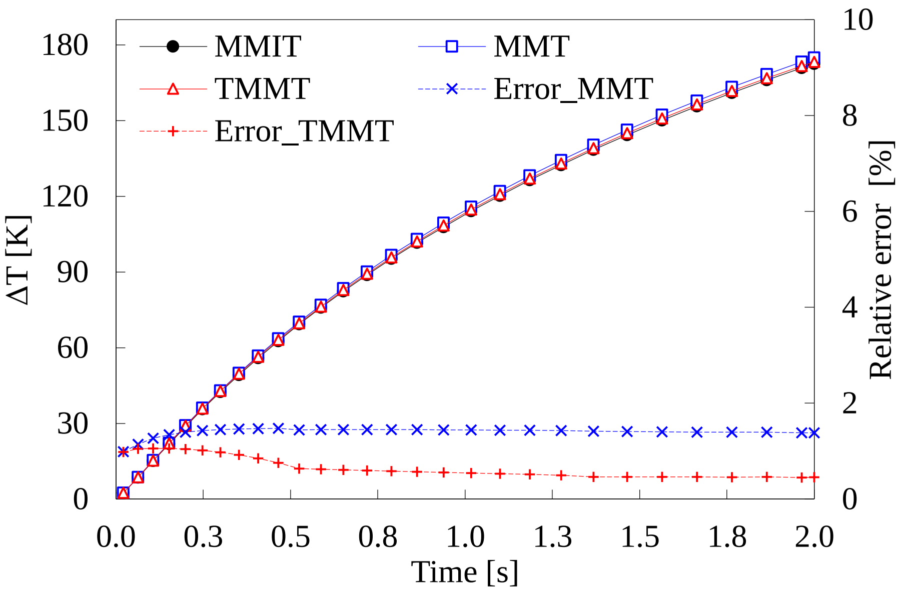
# NUMERICAL EXAMPLES

## Results analysis:

- The activation of the rmin strategy leads to a global decrease of the time step.
- The accuracy of all algorithms is improved.
- However, the TMMT algorithms gives a lower error than the MMT.

## $r_{min}$ strategy activated




Relative temperature evolution obtained with the MMIT, MMT and TMMT algorithms, including relative error.

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# NUMERICAL EXAMPLES

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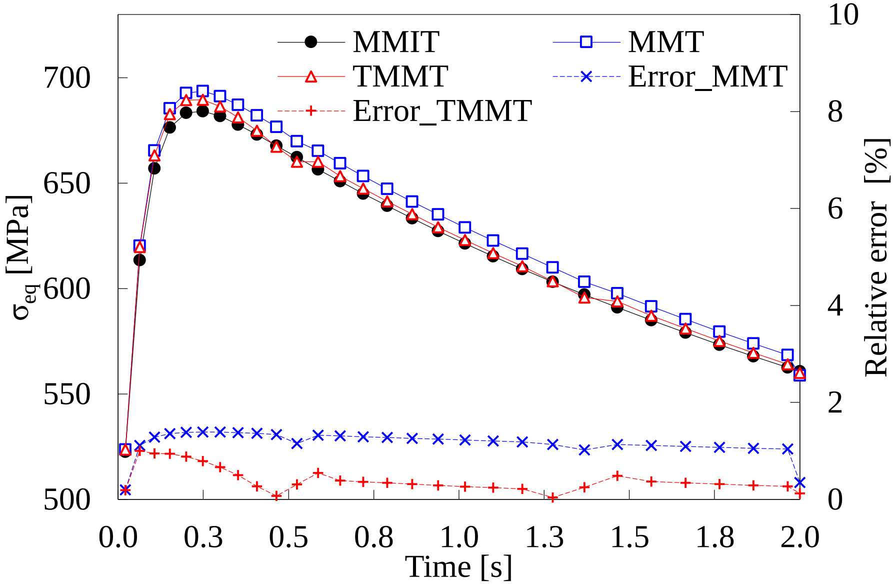
## $r_{min}$ strategy activated

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# SUMMARY

- A new staggered coupling algorithm, based on a isothermal approach, was proposed, in which both the thermal and the mechanical problem are solved sequentially.
- The finite element code developed has been validated using a classical numerical example.
- The performance of the proposed algorithm was discussed and compared with the one of classical strategies.

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# Thank you

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