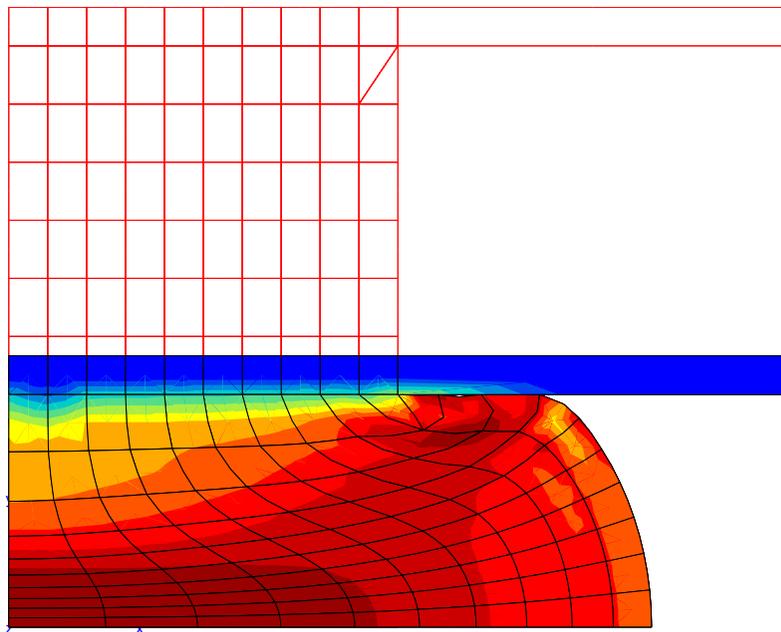


## Billet upsetting for time-independent and time-dependent plasticity



The purpose of this mini-project is to check the performance of an implicit algorithm in time dependent and time independent plasticity, by simulating the classical billet upsetting test proposed by Taylor [1]. The present algorithm is inspired from an algorithm for finite strain with isotropic behaviour [2]. The following files are available:

- mesh and input files needed to run a computation with a time independent model;
- source code of the time independent model.

The students will have to run the computations with various algorithmic conditions, and to compare the results with the reference given in the previous papers. A small strain version of the problem will be also considered to quantify the effect of the large strain formulation on the resulting loading curves. They will then have to develop the time-dependent version of the code, and to check the sensitivity of the results to strain rate.

*Keywords: Large deformations; J2 plasticity; viscous effect; code development.*

## Computation with a time independent model

### Go to directory `data`

The following files are available to run the computation:

- `cyl2.geof`, the geometry file represents a quarter of the cylinder section, which radius is 10 mm and height - 15 mm; We use the axisymmetry of the geometry as well as its symmetry relative to the central plane.
- `cyl2.inp`, the input file, that allows the user to prescribe the algorithm and the convergence parameters, the applied boundary conditions (symmetry condition, 9 mm vertical displacement<sup>1</sup> of the rigid plate), to manage the outputs and to point toward the material file;
- `j2ld.mat`, the material file, that defines the elastic (Young's modulus  $E=200$  GPa, Poisson's ratio  $\nu=0.3$ ) and plastic (initial yield  $\sigma_y=700$  MPa; plastic slope  $Q=300$  MPa) properties.

To run the computation use the command:

```
Zrun cyl2
```

During the run, check the behaviour of the numerical model (e.g. number of iterations, quadratic convergence). Various algorithms can be applied with various time steps:

- initial stiffness, the stiffness matrix is not recalculated during iterations - "eeeeee"
- modified Newton algorithm, the stiffness matrix is calculated at the first and second iterations - "p1p1p1";
- modified Newton algorithm, the stiffness matrix is calculated at the first, second and third iterations - "p1p2p2";

<sup>1</sup>9 mm applied to the half problem corresponds to 18 mm applied to the complete cylinder.

- true tangent operator, the stiffness matrix is calculated at each iteration "p1p2p3".)

The output file `cyl2.test` is a small formatted file that contains the history of the vertical reaction force at the symmetry line of the billet bottom. This can be compared with the reference in the directory `REF` by means of the `DRAW` script. To obtain the curve just run

```
.\ DRAW
```

To visualise the results launch the graphical user interface:

```
Zmaster cyl2
```

## Development of the time dependent version of the code

### Go to directory `Code/source`

There is two files in this directory, `J2LD.z` and `J2LDv.z`. The first one corresponds to the model that has been used for the time independent simulation. Open the file "J2LDv.z" (a clone of the "J2LD.z" file) and check that the integrated variables are the elastic strain tensor and the equivalent strain, and that the residuals are:

$$\mathcal{F}_e = -\underline{\underline{\mathbf{E}}}^* + \underline{\underline{\mathbf{E}}}_{n+1}^e + \underline{\underline{\mathbf{n}}}_{n+1} \Delta p \quad (1)$$

$$\mathcal{F}_p = J(\underline{\underline{\Lambda}} : \underline{\underline{\mathbf{E}}}_{n+1}^e) - R(p + \Delta p) \quad (2)$$

Check the partial derivatives, then modify the code to replace the present  $\mathcal{F}_p$  by a viscoplastic version,

$$\mathcal{F}_p = \Delta p - \Delta t \left[ \frac{J(\underline{\underline{\Lambda}} : \underline{\underline{\mathbf{E}}}_{n+1}^e) - R(p + \Delta p)}{K} \right]^n \quad (3)$$

The file `J2LDv.z` is a clone of `J2LD.z`. Edit this file, and make the relevant modifications of the residual and of the partial derivatives. Do not forget to introduce also two new material parameters (a new line `@Coefs K,n;`).

Go one level up, in the directory `Code` containing `library_files` and build a new dynamic library `libLocal.so` by means of the command

`Zmake`

## Investigation of the strain rate effect

**Go to directory** `data2`

This directory has the same structure as `data`. The material file `j2ldv.mat` can be modified, in order to investigate the strain rate effect. Check the modification of the load curve and of the distribution of inelastic strain for reasonable variations of  $K$  and  $n$ .

## Questions

1. How does the modification of the viscous parameters influence the resulting loading curve?

2. Is it reasonable to use a glued meshes in the region of permanent contact instead of two contacting meshes?
3. Which coefficient of friction corresponds to such an approximation?
4. Does this coefficient depend on the viscous properties? If yes, how?
5. For which value of the applied displacement it's reasonable to use a small strain approximation?

## References

- [1] L.M. Taylor and E.B. Becker. Some computational aspects of large deformation, rate-dependent plasticity problems. *Comp. Meth. Appl. Mech. Engng*, 41:251–278, 1983.
- [2] G. Weber and L. Anand. Finite deformation constitutive equations and a time integration procedure for isotropic hyperelastic–viscoplastic solids. *Comp. Meth. Appl. Mech. Engng*, 79:173–202, 1990.