COST 526

"Automatic Process Optimization in Materials Technology"

(APOMAT)

Half-Yearly Report

To be sent to **V.Tesch@access.rwth-aachen.de** until **August 31, 2003**

1. Reporting Period	**1.1.2003 – 31.6.2003**
Project title	Forging Process Optimisation
Project leader Organization	Lionel FOURMENT CEMEF, Ecole des Mines de Paris
Main collaborators involved	Mehdi Laroussi, Tien Tho Do

2. Funding Situation	
Amount of money received specifically for COST	730,6 Euros
Other resources partially used for the project	kEuros

3. International Collaboration

(mention group and type of work done in collaboration during the reporting period)

Participation in the Working Group Meeting in Brussels
Animation of Group: "Bulk product processing"

Work done in collaboration:
French National funded project "Optimat" gathering all the French partners of "Apomat" and with similar goals. Beginning of the project and definition of objectives.

4. Industry participation

(mention name of companies and work done in collaboration during the whole project)

Setforge, Sifcor (French forging companies) , Cetim (Technical Center of Mechanic Industry), CREAS

- Industrial forging examples for the definition of objective functions and optimisation parameters, and for validation of the sensitivity analysis in forging

5. Meetings, visits, exchange of scientists, short-term scientific missions	**Location, date**
Project meeting	Brussels, 26-27 May 2003

COST 526

"Automatic Process Optimization in Materials Technology"

6. Progress within the reporting period
(Not exceeding 3 pages, including tables and figures)

Abstract.
Sensitivities of objective functions with respect to several parameters are calculated for metal forming problems. Based on the differentiation of the discrete equations, the adjoint state method is used for non-steady processes with large deformations, contact evolution and remeshing. A backward analysis is carried out as a post-process, which requires additional storage of variables. The semi-analytical technique is used to compute the main derivatives. The accuracy of the sensitivity results is evaluated by comparison to finite difference scheme. During this last period, the work was focused on the determination of an industrial example and parameterization of the shape to be optimized.

Recent results
Previous works have made it possible to validate the sensitivity analysis based of the adjoint-state method for our non-steady metal forming applications. The following table summarizes the accuracy of the method (compared to finite difference schemes) for a simple upsetting problem without remeshing.

$\Delta\mu$ (in mm)	$\left(\frac{d\Phi}{d\mu}\Big\|_{ASM} - \frac{d\Phi}{d\mu}\Big\|_{FD\ forward}\right) / \frac{d\Phi}{d\mu}\Big\|_{ASM}$	$\left(\frac{d\Phi}{d\mu}\Big\|_{ASM} - \frac{d\Phi}{d\mu}\Big\|_{FD\ backward}\right) / \frac{d\Phi}{d\mu}\Big\|_{ASM}$	$\left(\frac{d\Phi}{d\mu}\Big\|_{ASM} - \frac{d\Phi}{d\mu}\Big\|_{FD\ central}\right) / \frac{d\Phi}{d\mu}\Big\|_{ASM}$
10^{-6}	0.36%	-0.25%	0.055%

Results of sensitivity analysis: no remeshing.

When remeshing takes place, simulations are less accurate. However, the sensitivity analysis exhibit similar accuracy like the direct simulation, as shown in the following table for the forging of a 3D tripod (complex 3D shape).

Number of remeshings	$\left(\Phi\Big\|_{5\ remeshings} - \Phi\Big\|_{remeshings}\right) / \Phi\Big\|_{5\ remeshings}$	$\left(\frac{d\Phi}{d\mu}\Big\|_{5\ remeshings} - \frac{d\Phi}{d\mu}\Big\|_{remeshings}\right) / \frac{d\Phi}{d\mu}\Big\|_{5\ remeshings}$
5 (minimum)	/	/
9	2.9%	1.5%
18	3.3%	4.8%
56	3.3%	5.3%

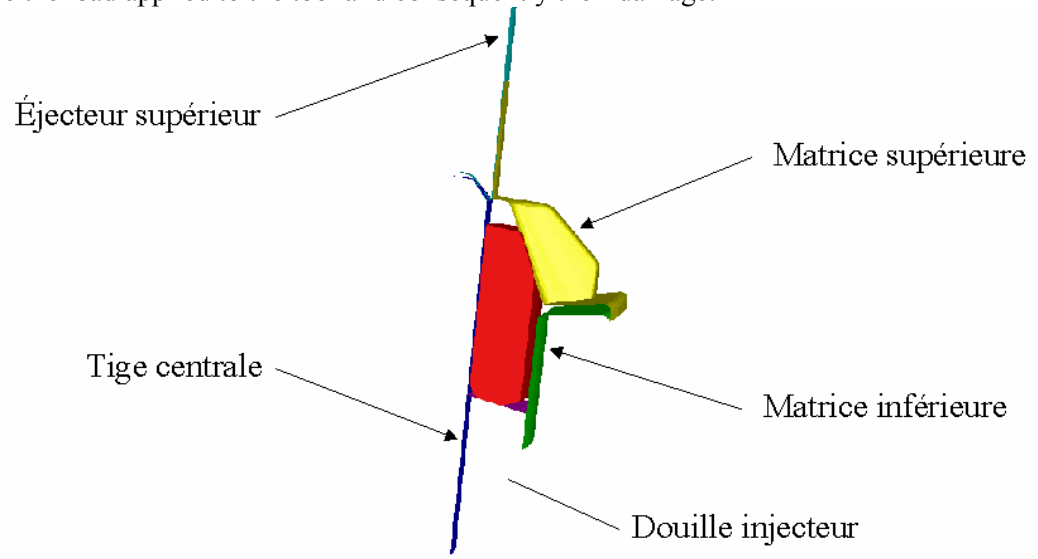
Results of sensitivity analysis: with remeshing.

The following table shows that these results do not require large computational times nor large memory space.

	Direct simulation	Adjoint simulation
Computational time	3min 45s	1min 42s
Storage	6.63 Mbytes	8.48 Mbytes

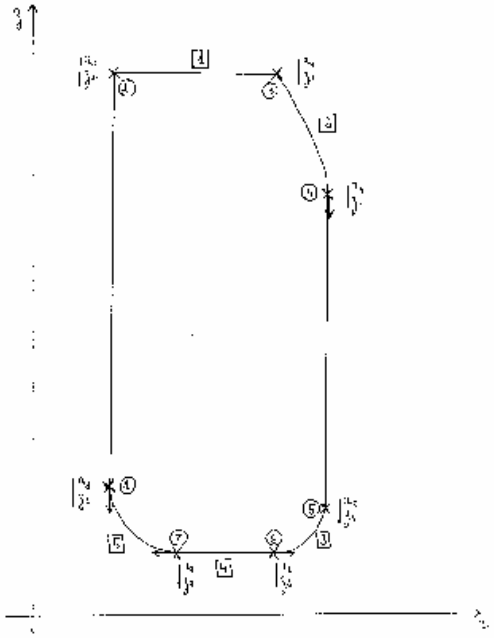
Computational time for the sensitivity analysis and additional memory requirements.

So, an industrial example has been proposed by an industrial partner of the project. It is the forging of a gear, as can be seen on next figure. The objective is to minimize the forging force. In fact, gear forging very often leads to premature tool failure or tool wears. Decreasing the forging force will also decrease the load applied to the tool and consequently their damage.



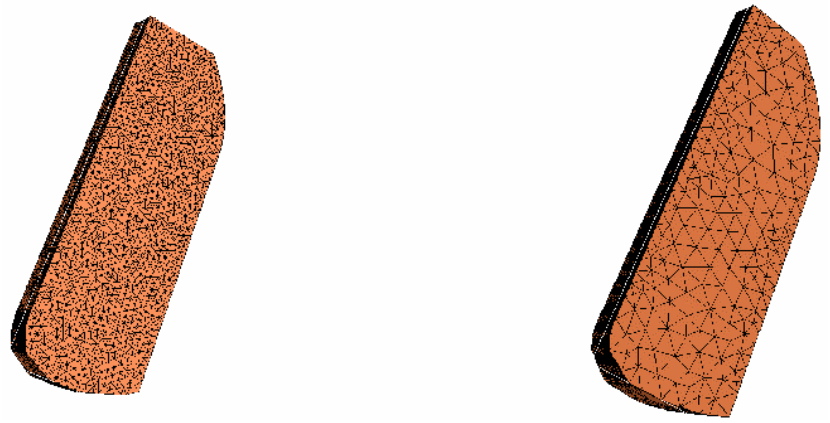
Presentation of the industrial test case.

The preform workpiece has an axisymmetrical shape. By changing this shape, but not the total volume of the workpiece, it is possible to modify the forging load. So the main issue is how to parameterize this axisymmetrical shape. Following industrial recommendations, the following parameterization has been selected.



Description of the workpiece to be optimized (projection on the radial plane) and definition of the optimization parameters of the 1D surface-curve.

Different procedures make it possible to transform this 1D curve into a 2D mesh and then into a radially extruded 3D mesh, as shown in the following figure.



Automatically generated 3D meshes from the parameterized 1D curve.

Work is going on for a proper parameterization of the 3D mesh in order to compute consistent derivatives for the adjoint-state method.

In the meantime, optimization using evolutionary algorithms has been investigated, and will be presented with more details in next report.

7. List of publications

a) Published

M. LAROUSSI, L. FOURMENT « The adjoint state method for sensitivity analysis of non-steady problems. application to 3d forging » in press: Int. J. of Forming Processes, vol. xxx, n°xxx, xxx, (2003)

S. H. CHUNG, L. FOURMENT, J. L. CHENOT, M. HWANG “Adjoint state method for shape sensitivity analysis in non-steady forming applications”, in press: International Journal for Numerical Methods in Engineering (2003)

M. LAROUSSI, L. FOURMENT « Sensitivity Analysis of 3D Forging using the Adjoint State Method : Extension to folds detection and die filling », VII International Conference on Computational Plasticity, COMPLAS, Barcelonna, April 7-10 2003

b) Submitted for publications

Nothing new submitted during the reporting period

c) In preparation

Ph. D. thesis of Mehdi Laroussi “The adjoint state method for the calculation of the sensitivity analysis derivatives: application to non-steady 3D forging”