



**COST 526**  
**“Automatic Process Optimization in Materials Technology”**  
**(APOMAT)**  
**Half-Yearly Report**

To be sent to [V.Tesch@access.rwth-aachen.de](mailto:V.Tesch@access.rwth-aachen.de)

<b>1. Reporting Period</b>	<b>01.01.2005 –30.06.2005</b>
Project title	Forging Process Optimization
Project leader Organization	Lionel FOURMENT CEMEF, Ecole des Mines de Paris
Main collaborators involved	Tien Tho Do, Abderamane Habbal

<b>2. Funding Situation</b>	
Amount of money received specifically for COST	730.6 kEuros
Other resources partially used for the project	kEuros

<b>3. International Collaboration</b> (mention group and type of work done in collaboration during the reporting period)
<b>Work done in collaboration:</b> French National funded project "OPTIMAT" gathering all the French partners of the project "APOMAT" for similar goals.

<b>4. Industry participation</b> (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, ASCOMETAL

<b>5. Meetings, visits, exchange of scientists, short-term scientific missions</b>	<b>Location, date</b>
3 months training of Martijn Bonte for exchanging results about optimization algorithms	CEMEF – Ecole des Mines de Paris May to August 2005

## 6. Progress within the reporting period

(Not exceeding 3 pages, including tables and figures)

Another optimization case has been handled during the last semester in order to evaluate the efficiency of the optimization algorithms presented in the previous half-year report. This case consists in the forging of a spindle, called "Spindle" in French.

### 1 CASE PRESENTATION

This is a two consecutive steps forging case: first a preform is made by upsetting between axisymmetrical forging tools, and is subsequently forged to produce the final product with real 3D tools. Note that only 1/6 of the upper half of the product is depicted since the spindle is symmetric.

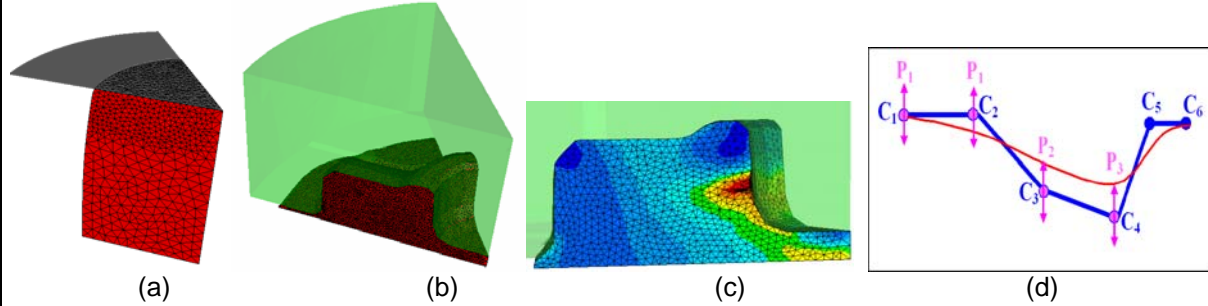


Figure 1: Forging a spindle (a,b) – Formation of a folding defect (c) – Parameterization of preform tool using a B-spline (d)

To evaluate whether the final product can be made in the factory, a (FEM) calculation was performed using the FE code Forge3. Figure 1.a and Figure 1.b show the FE models after the two forming steps. One full simulation of the spindle forging takes about four hours to run on an Intel Pentium IV desktop computer with 1GB memory. In Figure 1c, we can observe that a folding defect occurs, which deteriorates the final product quality. The depicted quantity is the equivalent plastic strain rate at the free surface of the product.

To overcome the folding defect, it is proposed to optimise the geometry of the preform with as an optimisation goal to minimise the equivalent plastic strain rate at the free surface during forging. The objective function is formulated as follows:

$$\Phi_{fold} = \frac{1}{t_{end} - t_0} \int_{t_0}^{t_{end}} \left( \frac{1}{\partial\Omega_{ft,ref}} \int_{\partial\Omega_{ft}} \left( \frac{\dot{\epsilon}}{\dot{\epsilon}_{ref}} \right)^\alpha ds \right)^{1/\alpha} dt$$

$t$  denotes the time,  $\partial\Omega_{ft}$  is the free surface of the discretised domain at time  $t$  and  $\partial\Omega_{ft,ref}$  the reference free surface at time  $t = t_0$ .  $\dot{\epsilon}$  and  $\dot{\epsilon}_{ref}$  are the equivalent strain rate and a reference equivalent strain rate and  $\alpha$  is an amplification factor, which is selected to be equal to 10.

In this case, the tool of the first forging step (axisymmetric, to be optimized) is parameterized in 2D by a B-spline shown in the Figure 1d as the thin red line. This B-spline is controlled by  $N$  control points  $C_i$ . These points can be fixed or active. The number of parameters  $P_j$  to be optimized can be chosen through the number of the active control points, these active points can move together or separately. If they move together, they are considered as only one parameter. All the parameters are allowed to vary between -10 and 20mm. The Figure 2d presents an example of a B-spline with 3 parameters and 6 control points (in which,  $C_1$  and  $C_2$  move together, they are considered as only one parameter  $P_1$ ).

### 2 OBTAINED RESULTS

We consider this optimization case with 2, 3 and 5 parameters for testing the algorithms.

#### a. Case with 2 parameters

Table 1 presents the obtained results for the case with 2 parameters. The table shows for all algorithms the number of the FEM calculation  $N_{opt}$ , which gave the optimal settings, as a fraction of the total number of simulations  $N_{tot}$  performed for a specific algorithm. Additionally, it presents the optimal design variable settings, corresponding objective function values with the amelioration percentage with related to the reference case and answers the question whether the folding defect has been solved or not. The convergence of the optimisation algorithms is depicted in Figure 2a.

According to Table 1 and Figure 2a, all optimisation algorithms reduce folding with related to the reference situation. All objective function values are lower than the reference value of 10.49.

The table and convergence plot present, however, that several optimisation algorithms perform better than others. The iterative BFGS algorithm is outperformed by the other algorithms. The *Figure 2b* shows the response surface obtained by Matlab, it is constructed with the value of the points obtained from all of the optimization algorithms. This figure demonstrates that our optimization problem has many extrema. This explains the reason why the BFGS algorithm is outperformed by other algorithms, BFGS is a local algorithm: it finds the optimum closest to the location where it is initialised and this is most of the times not the global optimum. Hence, a suboptimal result is obtained. The algorithm SCIP also finds a satisfactory solution, but not the best one. However, it is still a promised algorithm. The Metamodel Assisted Evolutionary Strategy and the two hybrid algorithms AGMGC, AGMGO are global algorithms and they consequently obtain lower function. On the other hand, the less optimal results of BFGS are obtained at significantly lower computational costs: it finds its optimum after only 7 calculations, while the other algorithms need many more simulations. In the case of the spindle, however, the folding defect is still present after optimisation by the BFGS algorithm. Hence, this algorithm does not live up to the expectation that the folding problem can be solved by optimisation.

	$Nb_{opt}/Nb_{total}$	$P_{1opt}$	$P_{2opt}$	$\Phi_{fold min}$	Amelioration (%)	Is the folding defect eliminated?
<b>Case REF</b>	1/1	0	0	10.49	0	No
<b>BFGS</b>	7/14	6.99	18.41	10.20	-2.8	No
<b>SCPIP</b>	8/24	1.03	0.47	9.29	-11.4	Yes
<b>AGMGC</b>	16/48	-8.47	-4.38	9.13	-13.0	Yes
<b>AGMGO</b>	20/48	-5.65	-7.52	9.00	-14.2	Yes
<b>ES-Meta</b>	30/48	-7.87	-10	8.14	-22.4	Yes

Table 1 : Results of optimizing Spindle with 2 parameters

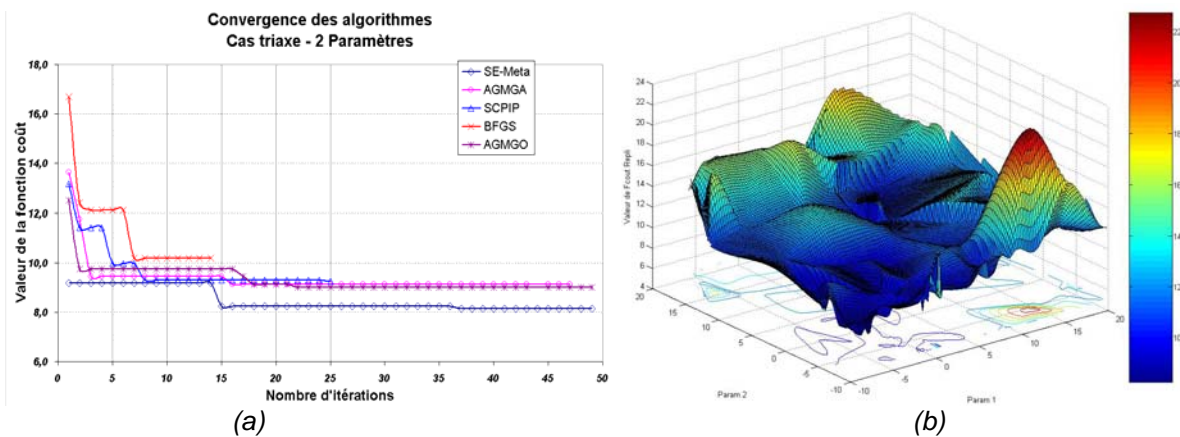


Figure 2: a: convergence of the different algorithms and response surface; b: response surface of the problem drawn with Matlab, using values evaluated with the different algorithms.

b. Case with 3 parameters :

In order to verify the capacity of evolutionary algorithms to handle several parameters, we try to solve the previous problem with 3 parameters. Obtained results are presented in Table 2. These results show once more the efficiency of evolutionary algorithms: ES-Meta finds a very much better solution with respect to the two gradient based algorithms. In addition, the obtained results are found within a limited number of objective function evaluations (less than 50), and the folding defect is eliminated. This demonstrates that evolutionary algorithms can be utilized for solving metal forming optimization problems.

	$Nb\ \acute{e}val/Nb\ \acute{e}val\ total$	$P_{1opt}$	$P_{2opt}$	$P_{3opt}$	$\Phi_{repli min}$	Le repli est-t-il enlevé ?
<b>Cas REF</b>	1/1	0	0	0	10.49	Non
<b>BFGS</b>	3/12	7.02	2.92	6.55	10.25	Non
<b>SCPIP</b>	9/12	-4.25	-6.01	-3.07	9.17	Oui
<b>Se-Meta</b>	30/48	-7.26	-3.84	-10	8.35	Oui

Table 2 : Optimization results of the case Spindle with 3 parameters

ACKNOWLEDGEMENTS

The contributions of Michael Emmerich from the Dortmund University (Germany) within the "APOMAT"

COST 526 project, and of the Ascoforge Safe company are gratefully acknowledged.

## **7. List of publications**

### **a) Published**

### **b) Submitted for publications**

### **c) In preparation**

- Thesis of Tien-Tho DO
- Article for the Revue Européenne de Mécanique Numérique (REM N)