



COST 526

**“Automatic Process Optimization in Materials Technology”  
(APOMAT)**

**Half-Yearly Report**

<b>1. Reporting Period</b>	<b>1.7.2002 – 31.12.2002</b>
<p>Project title Optimization of Sheet Metal Blanking and Bending Processes: Application to the Forming of High Strength Steel Security Parts</p> <p>Project leader : Pr Alain <b>Potiron</b> Organization Ecole Nationale Supérieure d'Arts et Métiers 2 boulevard du Ronceray BP 3525 49035 Angers France Main collaborators involved</p>	
<b>2. Funding Situation</b>	
Amount of money received specifically for COST	kEuros
Other resources partially used for the project	1,5 kEuros
<b>3. International Collaboration</b> (mention group and type of work done in collaboration during the reporting period)	
Participation in the Working Group Meeting in Budapest + project progress report	
NO	
<b>LASQUO ISTIA Angers University (Dr Ridha Hambli)</b> Type of work : Numerical Design of Experiments. Tests of numerical optimization algorithms with ABAQUS software.	
<b>4. Industry participation</b> (mention name of companies and work done in collaboration during the whole project)	
<b>Société DEVILLE S.A.</b> Type of work : Test specimens supply for experiments. Straightening process identification of the sheet-metal.	
<b>5. Meetings, visits, exchange of scientists, short-term scientific missions</b>	<b>Location, date</b> OPTIMAT French Ministry program in Paris

## 6. Progress within the reporting period

During the preceding period, the identification of the material was investigated. The actual reporting period deals with the identification of the process parameters happening in the optimization of the bending stage.

The main functions to be optimized are the sheet metal spring back, the residual stresses field and the material damage induced by the bending.

The process optimization in the case of a L-bending operation needs the definition of some objective functions. Generally in industry, an accurate final geometry must be obtained and this is achieved by minimizing the spring back angle.

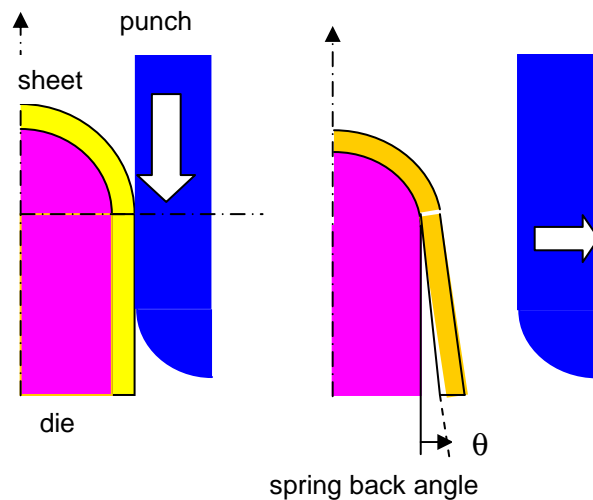
Among several models in literature we retain the following one named as Montfort-Bragard model :

The hypothesis concerns the material behavior for which the stress/strain evolution is :

$$\sigma = \sigma_y + (\sigma_u - \sigma_y)(1 - e^{-k' \epsilon^{pl}}) \quad (1)$$

$\sigma_y$  is the yield stress and  $\sigma_u$  is the ultimate tensile stress.

If it is supposed that the sheet is plastically deformed at the corner,  $\epsilon^{pl}$  is the plastic strain;



a- When the damage is not accounted for,

The plastic moment is computed through the sheet thickness in the form of :

$$M = \frac{bt^3}{4\beta} \left\{ \frac{\sigma_u}{2} + \frac{\sigma_u - \sigma_y}{k^2 \beta^2} (e^{-k\beta} (1 + k\beta) - 1) \right\}, \quad \beta = \frac{t}{2R}$$

R is the radius of the middle line =  $R_{die} + \frac{1}{2} t$

b and t are the sheet width and thickness.  $k'$  is a material parameter to be identified by suitable tensile tests. In that case, the spring back angle is computed by the formula :

b- When the damage is accounted for, with the linear following law :

$$D = H_G \epsilon^{pl}$$

The plastic moment is computed through the sheet thickness in the form of :

$$M = \frac{bt^3}{4\beta} \left\{ \frac{\sigma_u}{2} + \frac{\sigma_u - \sigma_y}{k^2 \beta^2} (e^{-k\beta} (1 + k\beta) - 1) \right\} - M_D$$

$$\text{with } M_D = 2bR^2(\alpha_u - \alpha_y)H_G \left( \frac{\beta^3}{2} - \frac{2}{k^3} + \frac{1}{k} e^{-k\beta} \left( \beta^2 + \frac{2\beta}{k} + \frac{2}{k^2} \right) \right)$$

Computation of the spring back angle

In both cases, accounting or not for the material damage, the elastic spring back angle is computed by the following relation :

$$\alpha_{sb} = \frac{R\alpha}{E \frac{bt^3}{12}}, \quad \alpha \text{ is the theoretical bent angle}$$

Where E is the Young modulus for a given damage value ( $D = 0$  or  $D \neq 0$ )

Optimization

In the case of an objective function relied to the spring back angle, the optimization problem reads :

Minimize  $\alpha_{sb}(R, t, \alpha, E, D)$

subjected to the following constraints

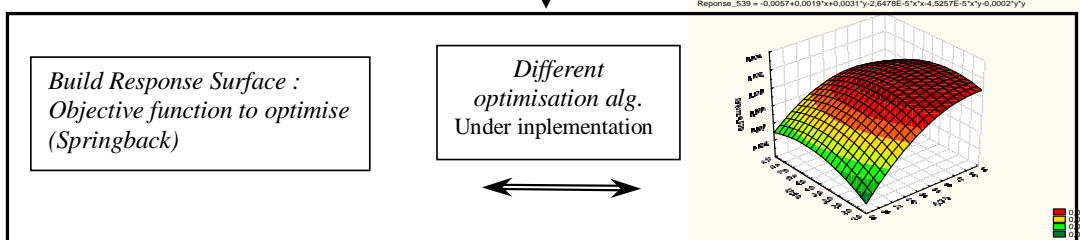
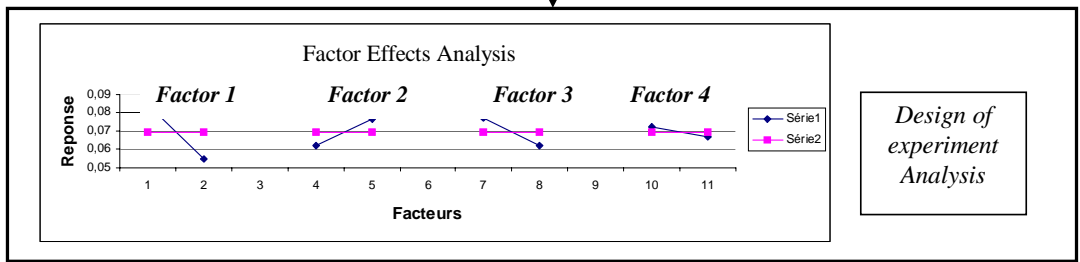
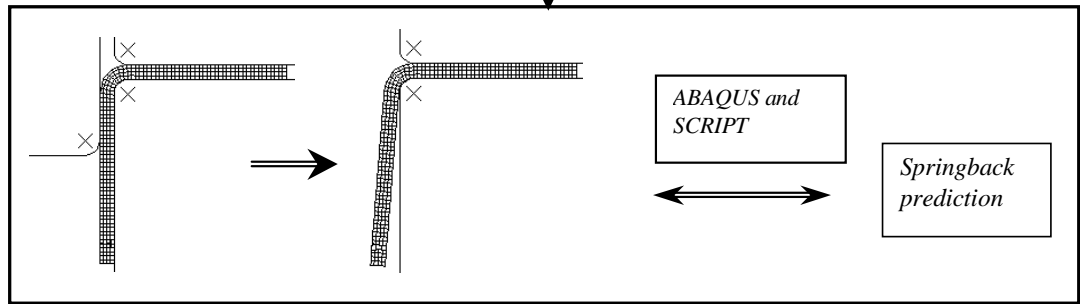
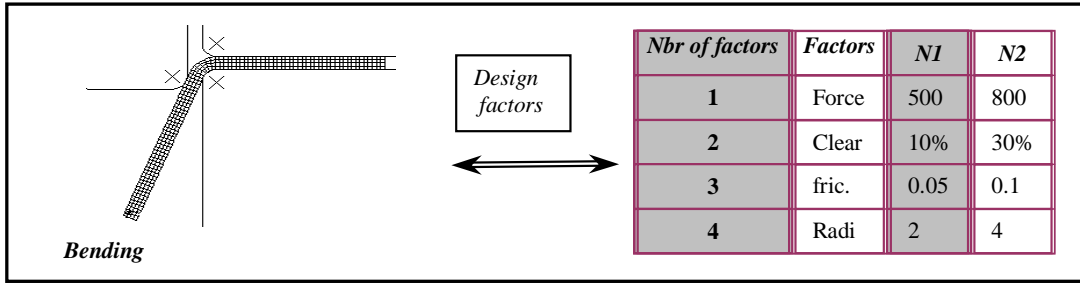
$D(\alpha^{pl}) \leq D_{crit}$  (in order to avoid material failure)

$$\alpha^{pl} \leq \alpha$$

This is to be implemented by means of Fortran algorithms. This approach is devoted to a feasible domain restriction in order to minimize the number of numerical steps when using genetic algorithms for example. A sensitivity analysis can be carried out by a straight forward calculation.

In an other hand, the LASQUO laboratory which is associated to the research, works in the field of the optimization by means of design of experiments. A feasible approach has been developed as follows.

The following scheme shows the main features in order to optimise the bending parameters, that is the punching force, the clearance, the friction coefficient and the die radius..



**Inputs :** *Differents bending factors in a parametric form*  
**Outputs :** *Springback of the sheet for different factors combination*

**Objective function :** Built obj Funt. Using Response Surface Technique

**Optimisation :** Application of Alg. (Gradient methods, simulated annealing, Genetic Algo. methods)

**PARAMETRIC PROGRAMMING USING ABAQUS AND ABAQUS SCRIPT**

## 1- Input factors in parametric way :

```
*PARAMETER
Clea= 5.    ** Tool Clearance
Fric=0.10  ** Friction coefficient
Radius=2.  ** Die corner Radius
```

## 2- Coding the factors : Radius example

```
*Surface, type=SEGMENTS, name=diesurf, fillet radius=<Radius>
START,      0.,      -54.
LINE,       0.,       0.
LINE,       50.,      0.
```

## 3- Script to generate a given number of simulation according a

```
study1 = parStudy (par=[' Clea ', ' Fric ', 'Radius '])
#
study1.define (CONTINUOUS, par=' Clea',domain=(0., 4.))
study1.define (CONTINUOUS,par=' Fric ',domain=(0.05,0.15))
study1.define (CONTINUOUS,par=' Radius ',domain=(2.0,4.0))
#
study1.sample (VALUES, par=Clea, number =3)
study1.sample (NUMBER, par= Fric, number=3)
study1.sample (NUMBER,par= Radius ', number=3)
study1.combine (MESH, name='Design_Experiment')
```

## design of experiments table :

## 4- Results

Radius	Clearance	Friction	Node displacement
0.,	2,	0.05,	47.8065,
4.,	2,	0.05,	43.78,
0.,	2,	0.15,	47.8376,
4.,	2,	0.15,	43.7566,
0.,	4,	0.05,	47.5607,
4.,	4,	0.05,	42.8844,
0.,	4,	0.15,	47.5955,
4.,	4,	0.15,	42.8674,

In the table, the displacement of the back point of the bent leg represents a measure of the spring back in the bending process. It can be observed that the last choice of the parameters values leads to the minimum spring back angle.

## 7. List of publications

### a) Published

HAMBLI R. and POTIRON A., "Evaluation of springback in L-bending processes including damage effects", TSS International Conference on Advances in Mechanical Engineering, March 18 - 20, 2002, Hammamet, Tunisia.

Mkaddem A., Potiron A., Boude S., "Straightened modification of 0.09% sheet metal carbon steel - micro hardness characterization in bending process", TSS International Conference on Advances in Mechanical Engineering , March 18-20, 2002, Hammamet e Tunisia.

Mkaddem A., Hambli R., Badie-Levet D., "Experimental determination of damage laws for high strength low alloy E420 HSLA steel using inverse technique", TSS International Conference on Advances in Mechanical Engineering , March 18-20, 2002, Hammamet - Tunisia.

Mkaddem A., Potiron A., Lebrun J-L. "Straightening and bending process characterization using Vickers micro hardness technique", International Conference of Advanced Technology of Plasticity, Oct.27-Nov. 31, 2002, Proc. Vol.1- p 631-636 Institute of Industrial science, The University of Tokyo Komaba - Japan.

### b) Submitted for publications

A. Mkaddem, A. Potiron, and S. Boude, "A comparison between experimental, numerical and theoretical springback angle in wiping die bending process" VII International Conference on Computational Plasticity COMPLAS 2003, E. Oñate and D. R. J. Owen (Eds) © CIMNE, Barcelona, 2003 (accepted, to be presented)

A. Mkaddem, R. Hambli, A. Potiron "Comparison between Gurson and Lemaître damage models in wiping die bending process". Jour, (accepted with revisions)

### c) In preparation