COST 526

"Automatic Process Optimization in Materials Technology"

(APOMAT)

Half-Yearly Report

1. Reporting Period	**1.8.2004 – 1.2.2005**
Project title	**Optimization of Sheet Metal Blanking and Bending Processes: Application to the Forming of High Strength Steel Security Parts**
Project leader	**Pr Alain Potiron**
Organization	Ecole Nationale Supérieure d'Arts et Métiers 2 boulevard du Ronceray BP 3525 49035 Angers France

2. Funding Situation	
Amount of money received specifically for COST	kEuros
Other resources partially used for the project	4 kEuros

3. International Collaboration (mention group and type of work done in collaboration during the reporting period)
Participation in the Working Group Meeting in Brno + project progress report Yes

4. Industry participation (mention name of companies and work done in collaboration during the whole project)
Société DEVILLE S.A. **Type of work : Test specimens supply for experiments. Straightening process identification of the sheet-metal.**

5. Meetings, visits, exchange of scientists, short-term scientific missions	**Location, date** OPTIMAT French Ministery program in Besançon November 2004
Dr Slim Ben Elechi- Laboratoire Roberval UTC Compiègne BP 20529 - 60205 Compiègne (France)	February 15^{tht} – February 22th - 2005

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

The project concerns the optimisation of security parts in automotive industry.
During the previous period, the optimization techniques concerning the process parameters influencing the part bending, were developed. The optimization algorithms are now based on Abaqus F.E. code simulations. Design and Analysis of Computer Experiments are developed with the use of Response Surface. The optimal process parameters values are found with Moving Least Squares and Evolution Strategies methods.

The study is concerned with the optimization of the bending-process parameters, in view of stress and damage minimisation in special specimens.

The main functions to be optimized are the von Mises equivalent stress and the material damage resulting from the bending operation.
Specimens with a central oblong hole were blanked out from a sheet, after what they were bent in a mechanical press (fig. 1).

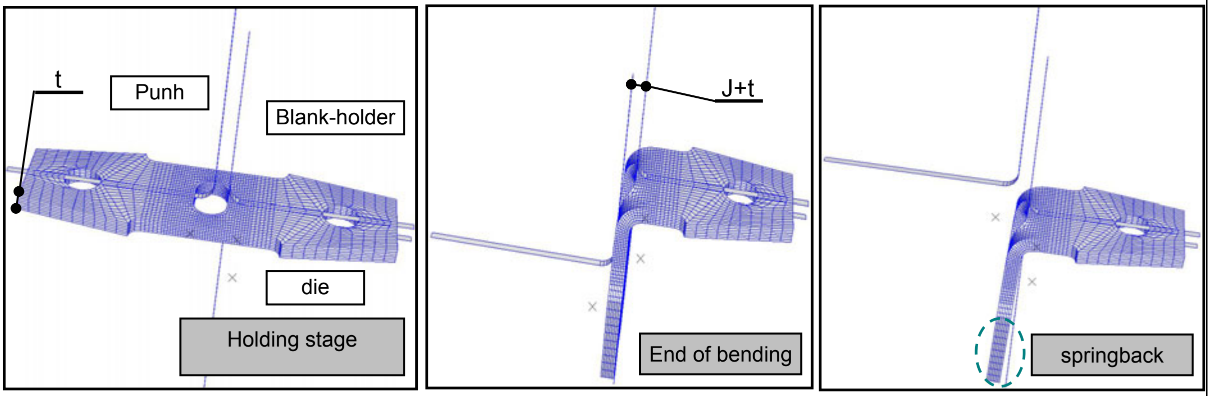


Figure 1- Bending Process Simulation

1- Objective functions of the bending operation and optimisation problem

The objective functions are the maximum von Mises equivalent-stress σ_{vM} and the maximum material damage *D*. They occur at the corner of the central hole: points 1 and 6 in figure 2.

The process parameters are the design variables $\overline{J}$ and $\overline{R}$, i.e. the relative clearance between the blank and the tools and the relative die radius. The goal is to minimise $\overline{\sigma}_{vM}$ and *D*. The optimization problem reads :

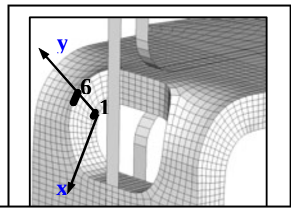


Figure 2- Central hole

Minimize $\overline{\sigma}_{vM}\ (\overline{J}, \overline{R})$ with $\overline{J} = \frac{c}{t}; \overline{R} = \frac{r_d}{t}; \overline{\sigma}_{vM} = \frac{\sigma_{vM}}{\sigma_y}$ (1)

subjected to the following constraints:
$r_{mini} < r_d < r_{Maxi}$; $J_{mini} < c < J_{Maxi}$
σ_y *is the yield stress, c* is the clearance and r_d is the die radius.

2- Response surface methodology

The surface response method is used in order to optimise the two objective functions $\overline{\sigma}_{vM}$ and *D*. The approximation are fourth order polynomials:

$$\tilde{Y}_1 = \alpha_0 + \sum_{i=1}^{n} \alpha_i x_i + \sum_{i=1}^{n} \alpha_{ii} x_i^2 + \sum_{i<j}^{n} \alpha_{ij} x_i x_j + \sum_{i=1}^{n} \beta_{ii} x_i^3 + \sum_{i=1, i\neq j}^{n} \beta_{ij} x_i^2 x_j + \sum_{i=1}^{n} \gamma_{ii} x_i^4 + \sum_{i=1, i\neq j}^{n} \gamma_{ij} x_i^3 x_j + \prod_{i=1}^{n} \xi x_i^2 \quad (2)$$

The x_i are the process parameters. They are determined by means of a full matrix of Design of Experiments resulting from the numerical F.E. simulations.

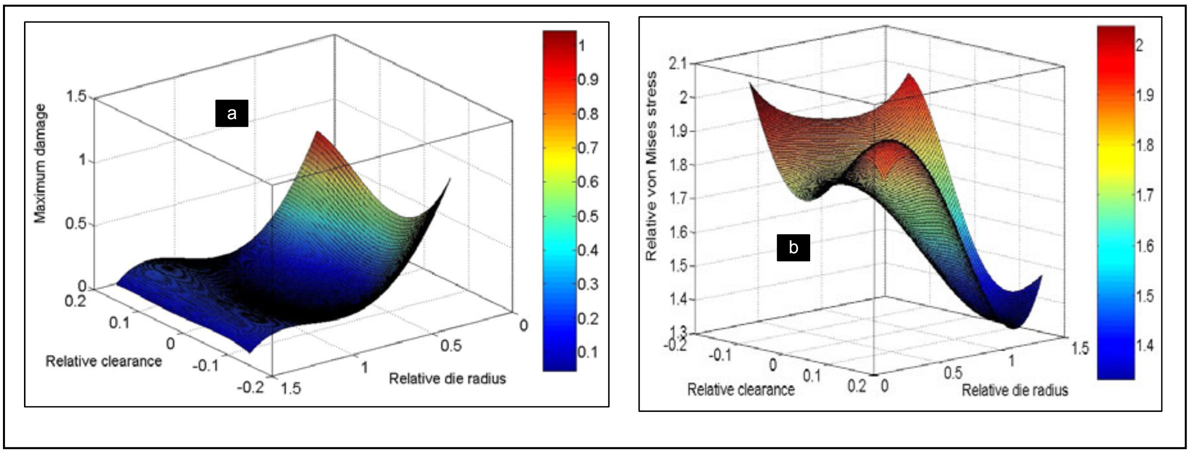


Figure 2- Response surface of (a) material damage (b) von Mises stress

3- Moving least squares method

The unknown function is approximated by a polynomial-based approximation in the form of:

$$\hat{y}(\mathbf{x}) = \mathbf{p}^{T}\{(\mathbf{P}[\boldsymbol{W}]\mathbf{P}^{T})^{-1}\times(\mathbf{P}[\boldsymbol{W}])\}\boldsymbol{f} \quad (3)$$

The n-dimensional vector **f** is defined as : $\mathbf{f}^T = [f_1 \;\; f_2 \;\; \dots \; f_i \;\; \dots \; f_n]$ and the f_i are the function values at n design points *(i=1,n)*

p is a vector of *k* monomials, **P** is a matrix containing *n* columns corresponding to the vectors $\mathbf{p}_i$ calculated at the *n* design points. **W** is a weighting coefficients matrix.

The optimum of the approximated function is found by solving the quasi-Newton equation:

$$\boldsymbol{H} \; \Delta\mathbf{x} = - \nabla\hat{y} \quad (4)$$

H is the Hessian matrix and ∇ŷ is the gradient of ŷ. At each iteration, the search point moves with a value Δ**x.** When Δ**x** is sufficiently small, the algorithmic loop stops.

4- Evolution Strategy

In *ES*'s, a population of individuals is created with μ parents and λ children. Each individual is represented by a vector ***X*** with *n* real components x_k representing its genotype ($\boldsymbol{X}\in\Re^n$) and the population evolves according to the operations of selection, mutation and cross-over.

The offspring represented by the vector $\boldsymbol{X}_N^{(g)}$ (index *N* for *new*), is obtained by adding to the parent $\boldsymbol{X}_O^{(g)}$ (index *0* for *old*) a random vector ***Z*** with normally distributed components ***Z*** ~N (**0**, **I**) ($\boldsymbol{Z}\in\Re^n$). For the generation (g) we have:

$$\boldsymbol{X}_N^{(g)} = \boldsymbol{X}_O^{(g)} + \sigma^{(g)}\boldsymbol{Z} \quad (5)$$

The selection is carried out by computing the objective function value until convergence:

$$X_O^{(g+1)} = \begin{cases} X_N^{(g)} \; si \; f(X_N^{(g)}) \leq f(X_O^{(g)}) \\ X_O^{(g)} \; otherwise \end{cases} \qquad (6)$$

In case of Covariance Matrix Adaptation, the parametric vectors are updated by transforming the vector $\boldsymbol{Z} \sim N(\mathbf{0}, \mathbf{I})$ by a square matrix $\sqrt{C}_{n \times n}$. The strategy is noted (□,□)-*CMA* and the mutation step is given by:

$$\boldsymbol{X}_k^{(g+1)} = \langle x \rangle_\mu^{(g)} + {}^{(g)} \sqrt{C}\, \boldsymbol{Z}_k \quad k \quad = \quad 1\ldots,$$
(7)

The steps of cross-over and selection are analogous to the previous ones and the optimum is reached when the objective function is minimum (maximum).

5- Results of the optimisation

5.1- Stress and damage minimisation

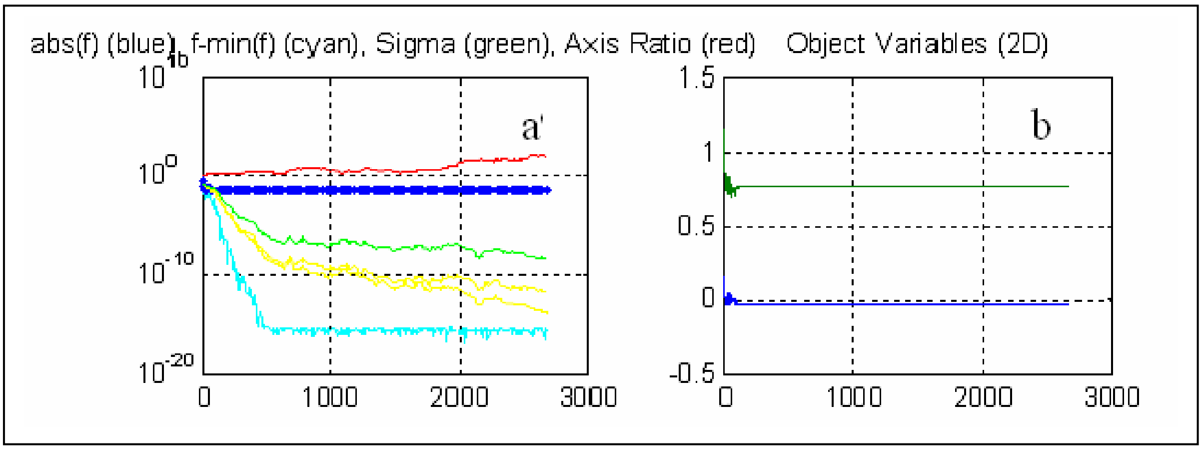


Figure 3- Damage minimisation with *E.S (a) Damage (b) process parameters*

The functions evaluations and the parameters evolutions can be shown on figure 3. It Is seen that the optimum is reached after few iterations.

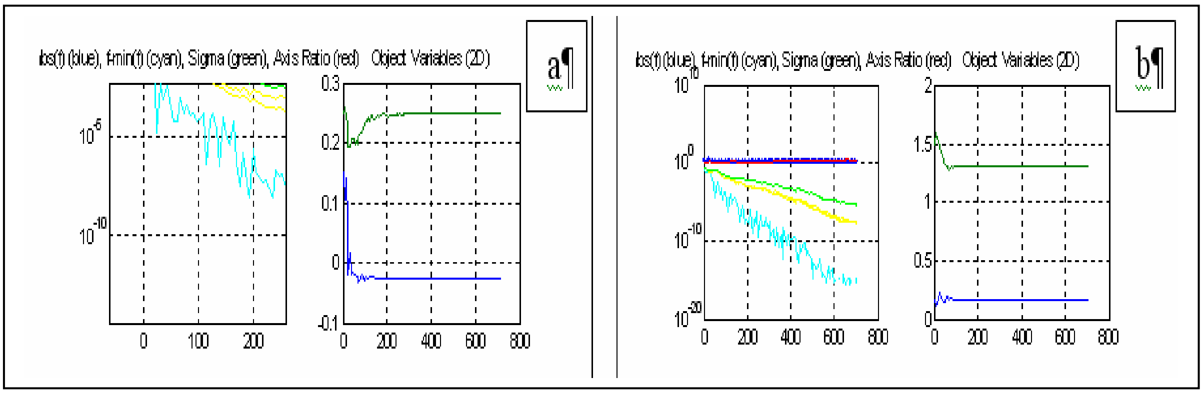
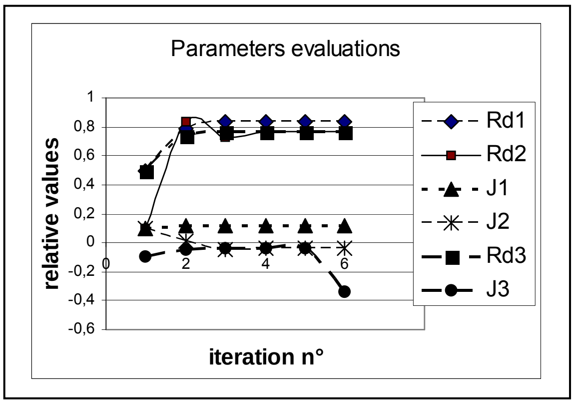


Figure 4- Stress minimisation with *E.S (a) - (b) two different initial points*

The figures (a) and (b) are obtained with two different initial point evaluations. The responses are different, showing that several tries are to be carried out.
In that case, the functions are smooth and the minimum value of the springback

angle is easily found by a direct differentiation.

The numerical predictions by means of *M.L.S* are shown in figure 5 below.



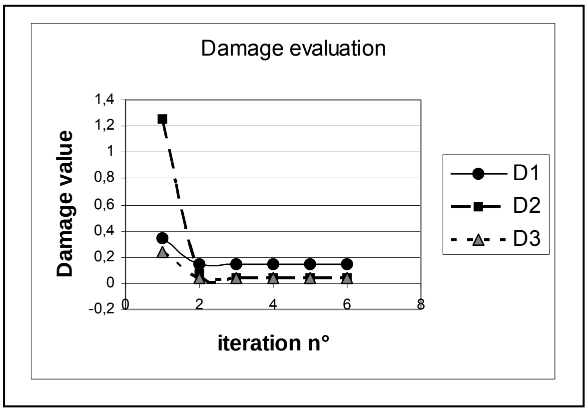


Figure 5- Parameters and damage prediction with *M.L.S*.

The values of the process parameters are well predicted in case of 3 initial points. The damage values predicted in the 3 cases are similar but the corresponding process parameters values are different. This is due to the shape of the response surface shown in figure 2a which is quite flat in the lower part.

6- Conclusion

The optimisation of the bending process in termes of process parameters are predicted by means of two optimisation techniques: the Moving Least Squares method and an Evolution Strategy. The two methods lead to the same results but it was found that the predictions are dependent on the choice of the initial points and errors estimates in each method.

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 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

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

Ridha Hambli, Alain Potiron, Abdessam Kobi "Application of design of experiment technique for metal blanking processes optimization", *Pages 175-180* Mécanique et Industrie Volume 4, Issue 3, Pages 159-327 (May - June 2003)

Ridha Hambli, Alain Potiron "Modélisation et découpage des tôles" Techniques de l'Ingénieur (in french) Vol BM 7 505, pp 1-18

A. Mkaddem, R. Hambli, A. Potiron "Comparison between Gurson and Lemaître damage models in wiping die bending process". Journal of Advanced Manufacturing Technology 2004 Vol 23 issue 5-6 pp 451-461

Mkaddem A., Boude S., Dal-Santo P., Potiron A.
Springback evaluations in wiping die-bending processes with experimental verification, International Conference on material forming ESAFORM 2004, Apr.28-30, Trondheim-Norway

Mkaddem A., Bahloul R.., Potiron A., Reszka M..
H.S.L.A. steel sheet metal characterisation for metal forming processes by using experimental approaches, International Conference on material forming ESAFORM 2004, Apr.28-30,Trondheim-Norway.

Bahloul R., Dal-Santo P Mkaddem A., Potiron A
Optimisation of springback predicted by experimenyal and numerical approach by using response surface methodology. Proc. Of 11th International Conference on Sheet-metal SHEMET 5-8 april 2005 Univ Erlangen Germany p; 753-760

Bahloul R., Dal-Santo P., Potiron A.
Optimisation of process parameters in wiping-die bending operation in order to minimise stresses and lemaître's damage. Proc. Of 8th ESAFORM Conference on material forming.27-29 april 2005; Cluj Napoca Romania p.159-162

Mkaddem A; Bahloul R.., Potiron A.
Numerical analysis and response surface method to investigate friction effects in sheet bending operation. Proc. Of 8th ESAFORM Conference on material forming.27-29 april 2005; Cluj Napoca Romania; p. 261-264

b) Submitted for publications

Mkaddem A., Bahloul R.., Potiron A HSLA steel characterization in sheet forming processes by using Vickers microhardness technique. Int. Journal of Mat. Processing Techn.

Mkaddem A., Bahloul R.., Potiron A Experimental approach and RSM procedure on examination of springback in wiping-die bending processes. Int. Journal of Mat. Processing Techn.

Mkaddem A., Bahloul R.., Potiron A Experimental and numerical investigation in the optimization of sheet products geometry, using RSM. Int. Journal of Mat. Processing Techn

c) In preparation

Mkaddem A., Bahloul R.., Potiron A., Influence of interface frictional design on sheet-metal bending operation. Numerical prediction of material damage and maximum bending force.