COST 526

"Automatic Process Optimization in Materials Technology"
(APOMAT)

Half-Yearly Report

To be sent to **V.Tesch@access.rwth-aachen.de** until

1. Reporting Period	**1.2.2005 – 1.8.2005**
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	**Main collaborators involved** Dr. Philippe Dal Santo; Riadh Bahloul (PhD) ; Ali Mkaddem (Researcher) ERT ENSAM Angers (France)

2. Funding Situation	
Amount of money received specifically for COST	kEuros
Other resources partially used for the project	3 kEuros

3. International Collaboration (mention group and type of work done in collaboration during the reporting period)
Participation in the Final Working Group Meeting in Morschach + project progress report
National Collaboration Use of MECALOG Optimisation Platform provided by MECALOG (RADIOSS Software) Dr Jena-Marc Faure (France)

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. Arrangement of Experimental shock device**

5. Meetings, visits, exchange of scientists, short-term scientific missions	**Location, date**
	Organisation of next final OPTIMAT meeting (French Research Ministry program) in Paris November 29th 2005

6. Progress within the reporting period

The project concerns the optimisation of security parts in automotive industry.
During the previous period, the optimization techniques concerning the part shape and the process parameters influencing the part bending, were developed. The optimisation 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, Evolution Strategies methods and Kriging

The study is concerned with the optimization of the bending-process parameters, in view of predicting the dynamical behaviour of representative special specimens.

The main functions to be optimized are: (i) the von Mises equivalent stress and (ii) the material damage resulting from the bending operation.
We want to maximise the unbending force corresponding to a sudden shock exerted by the security belt on the real security part. A simplification of the real part is realised in the form of specimens with a central oblong hole. were blanked out from a sheet, after what they were bent in a mechanical press (fig. 1).

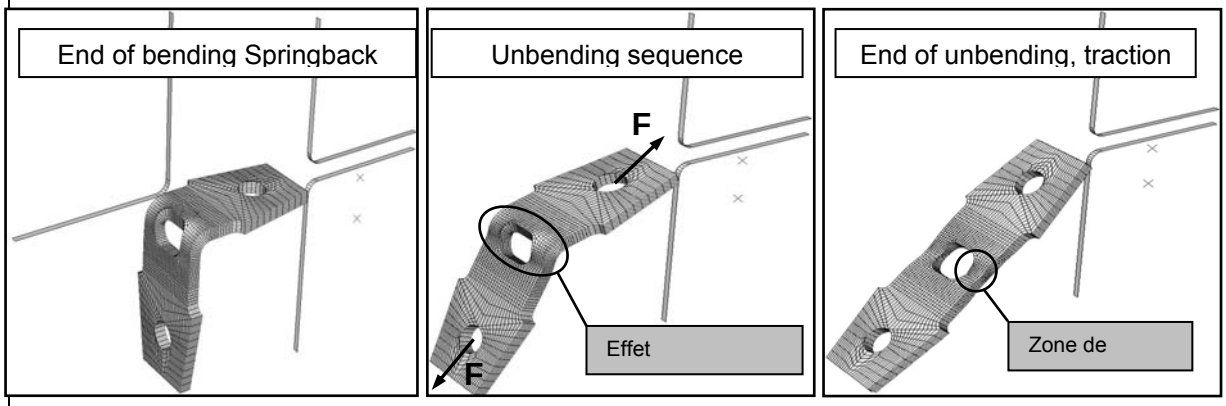

Figure 1- Simulation of Unbending Process

1- Objective functions of the Unbending operation and optimisation problem

The objective function is the unbending load which can be supported by the specimen.
The process parameters are the design variables $\bar{J}$ and $\bar{R}$, i.e. the relative clearance between the blank and the tools and the relative die radius. The goal is to maximise $\bar{F}_{vunb} = \frac{F}{S\sigma_y}$. *S* is the cross section area and σ_y is the yield stress. The optimization problem reads :

Maximize $\bar{F}_{unb}(\bar{J}, \bar{R})$ with $\bar{J} = \frac{c}{t}; \bar{R} = \frac{r_d}{t}; \bar{\sigma}_{vM} = \frac{\sigma_{vM}}{\sigma_y}$ (1)

subjected to the following constraints:

$r_{mini} < r_d < r_{Maxi}$; $J_{mini} < c < J_{Maxi}$ (2)

c is the clearance and r_d is the die radius.

2- Unbending force modelling

ABAQUS 3D modelling of the unbending loading allowed for the force evolution characterisation, shown in figure 2 below.

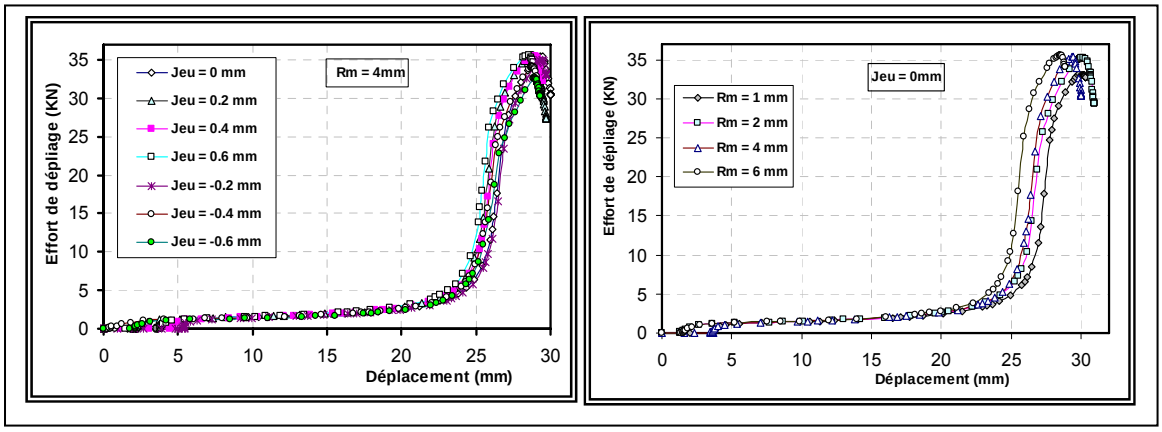

Figure 2- Unbending force evolution

Two regions are visible: (i) a low force growth corresponding to the straightening of the specimen (ii) a quick growth of the force corresponding to a tensile situation analogus to a tensile test of a flat specimen.

2- Response surface methodology

The surface response method is used in order to optimise the objective function $\overline{F}_{unb}$. The approximation are fourth order polynomials:

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

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.

The results are reported on figure 3

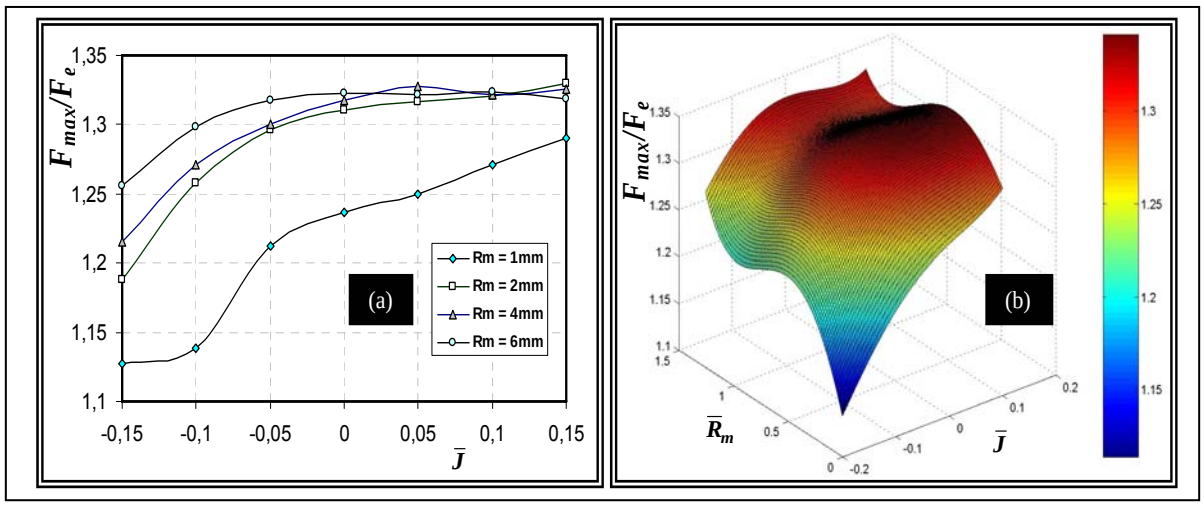

Figure 3- Relative force evolutions vs die radius and clearance (a)
Response surface (b)

The optimum point is clearly identified on figure 3b. The minimum value corresponds to a specimen bending with a die radius of 1mm which induces a high material damage value and macro cracks initiation.

4- Evolution Strategy

In *ES*'s, a population of individuals is created with parents and children. Each individual is represented by a vector $\boldsymbol{X}$ 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. (see HYReport 6)
The optimum is reached when the objective function is maximum.

5- Results of the optimisation

5.1- Unbending force maximisation

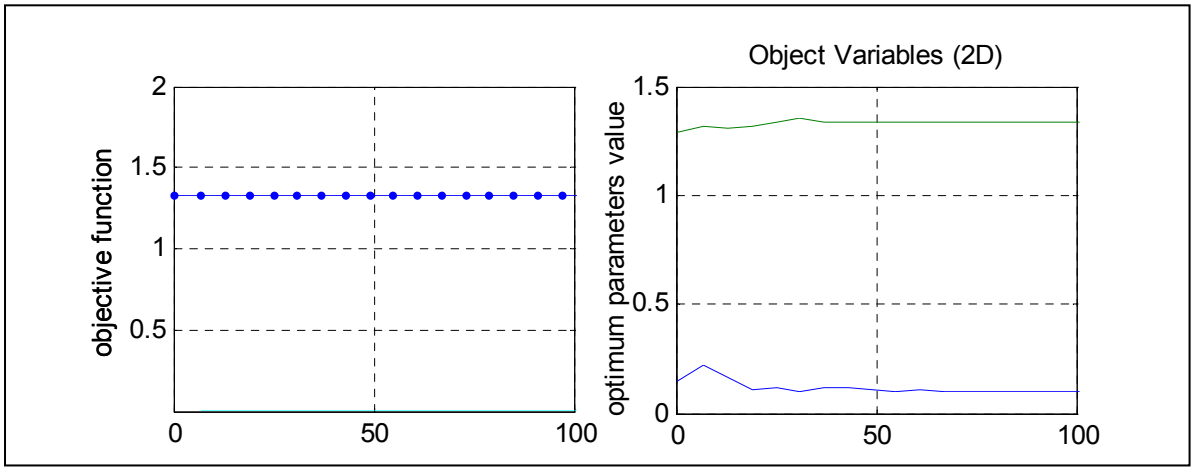

Figure 3- Force maximisation with *E.S (a) Reduced force (b) process parameters*

The functions evaluations and the parameters evolutions can be shown on figure 3. It Is seen that the optimum is reached after few iterations. Its value is 1.3286 and the process parameters are valued : $\overline{J}$ = 0.1; $\overline{R}$ = *1.3336* . *This can be compared to the values given in figure 3b. There are quite the same.*

6- Conclusion

The prediction of the unbending process in terms of process parameters are predicted by means of two optimisation techniques: the Response Surface 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 polynomial oder 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 experimental 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 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

R. Bahloul; S. Ben Eléchi; Ph. Dal Santo; H. Naceur; A. Potiron, Optimisation of bending process by means of response surface and moving least squares methods, Far East Journal of Applied Mathematics (Accepté_ Reference n° :050728)

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.