COST 526
"Automatic Process Optimization in Materials Technology"
(APOMAT)

Half-Yearly Report

1. Reporting Period	**1.7.2002 – 31.12.2002**
Project title	Optimization of Process Parameters in Sheet Metal Forming
Project leader Organization	**Dr. Catherine Knopf-Lenoir** Université de Technologie de Compiègne Laboratoire Roberval, UMR UTC-CNRS BP 20529 – 60205 Compiègne Cedex
Main collaborators involved	Prof. Jean-Louis Batoz, Dr Arnaud Delamézière InSIC, 27, Rue d'Hellieule 88100 Saint-Dié-des-Vosges Dr Hakim Naceur, UTC

2. Funding Situation

Amount of money received specifically for COST	0 kEuros
Other resources partially used for the project	
Funding from the french Ministery of Research (OPTIMAT project):	60 kEuros per year

3. International Collaboration
(mention group and type of work done in collaboration during the reporting period)

Participation in the Working Group Meeting in Budapest + project progress report
YES

4. Industry participation
(mention name of companies and work done in collaboration during the whole project)

5. Meetings, visits, exchange of scientists, short-term scientific missions	**Location, date**

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

WP2: Optimization with Inverse Approach (REFORM)

Optimization of material parameters
In the previous report, several optimization problems have been defined and solved by a mathematical programming approach: the thickness variation and the Forming Limit Diagram

were taken as objective function, and the design variables were associated to the shape of the blank contour and to the restraining forces. During this second step (July 2002 to december 2002), the same type of objective function is considered with a new type of design variables: the material characteristics are to be determined by the optimization procedure in order to find an ‘ideal’ material, i.e. a material allowing to obtain the required part without any defect. The strain hardening exponent n of the Hollomon law and the average anisotropy coefficient r are taken as design variables [1]. Since the FLC depends on these properties, we adopt a method based on the growth of an imperfection proposed by Graf and Hosford to update the FLC for each new material parameters during the calculation [2]

Wrinkling can be viewed as a bifurcation plastic buckling process. A simple criterion to estimate the risk of wrinkling in the curved deformed shell has been developed by Brunet *et al.* [3] based on the work of Hutchinson *et al.[*4], Neale *et al.* [5].The wrinkling risk factor is determined taking into account the actual geometry and the stress state, Hutchinson, Neale and Tugcu assumed that :

- Final configuration is a doubled-curved sheet with constant principal radii of curvature and constant thickness
- The state of stress is a uniform membrane state described by the two principal stresses
- The plastic buckling process is governed by the Hill bifurcation criteria
- Deformation theory of plasticity is assumed at buckling
- Any interaction between the sheet and die is neglected
- Localised phenomenon (sheet dimension and limit condition are forgotten)
- Buckling in a short wavelength mode (use of Donnell-Mushtari-Vlasov shallow shell theory)
- Brunet *et al.* [3] added :
- Ratio between the principal stresses remains identical between the prebuckling state and the plastic bifurcation state

The problem is highly non linear, its iterative resolution is time consuming without guaranty of convergence.
For a qualitative analysis :
Principal axes of the stresses coincide with the principal axes of curvature
An analytical resolution is done for a ratio of the principal stresses:

$$\alpha = \frac{\sigma_2}{\sigma_1}$$

with the radii of curvature R1 and R2 and the thickness h, the expression for the critical wrinkling stress follows :

$$\alpha' = \sqrt{1 - \frac{2\,\bar{r}\,\alpha}{1+\bar{r}} + \alpha^2}$$

$$\sigma_1^{cr} = K\left[\frac{1+\bar{r}}{\sqrt{3\left(1+2\,\bar{r}\right)}}\left(\frac{h}{R_2}\right)\sqrt{n}\,\left(\alpha'\right)^{1-1/n}\right]^n$$

For an element, the criterion for wrinkle formation tendencies f_e is defined as :

$$f_e = \frac{\sigma_1}{\sigma_1^{cr}}$$

If fe is greater than one, the wrinkling risk exists. An objective function J2 is defined as :

$$J_2 = \sum_{nelt} \begin{cases} \left(\frac{f_e - w}{w}\right)^2 & \text{if} \quad f_e \geq w \\ 0 & \text{otherwise} \end{cases}$$

where nelt = number of elements, w = an acceptable wrinkling risk.

To avoid failure and wrinkling we consider the function J combining the functions:
J1 based on the FLC:

$$J_1=\sum_{nelt}\begin{cases}(s-d)^2 & \text{if } (s-d)>0\\ 0 & \text{otherwise}\end{cases}$$

where d = distance between the point (□2, □1) of the element and the FLC
and J2 :

$$J=J_1+J_2$$

This objective function is minimized with a response surface method based on the diffuse approximation[6]. The general idea is the following:

a regular grid is defined on the design domain;

a starting point X^1 is chosen, and a local approximation is built using the p nearest neighbours of X^1 in the grid (Y1, Y2, ... Yp). The exact function is to be computed (FE analysis) at these points.

the minimum of this approximate function is then determined and taken as the next iterate.

At each iteration, the approximate function can use some previously calculated points, or new points of the current grid; in order to converge, it may be necessary to refine the grid locally.

A square box was proposed as benchmark for Numisheet' 93, for experimental studies and numerical simulations. Two material were tested: an aluminium (n=0.3593, r=0.6425) and a steel (n=0.2637, r=1.77). It was found experimentally that for the aluminium a failure occurred for a depth of 20 mm. We use the properties of the aluminium has starting point of the optimization procedure for a drawn part and a punch travel of 23 mm.
The safety margin s is taken as 0.05. The limit w is set to 5, closed to the value obtained for the risk wrinkling factor for the steel. For the initial properties some points of the FLD are above the secure FLC. After optimization using diffuse approximation with a 12×12 grid and 8 neighbours, the FLD is below the FLC (Figure 1) and the maximum wrinkling risk factor is less than 5. The solution (n=0.1943, r=1.9339) is obtained after 7 iterations and 26 function evaluations. Nevertheless, due to the choice of the objective function (sum of two penalty functions to avoid failure and wrinkling), this solution is not unique: J = 0 for any material satisfying the constraints. The use of an approximation allows the estimation of the feasible domain boundaries, giving all the admissible materials.

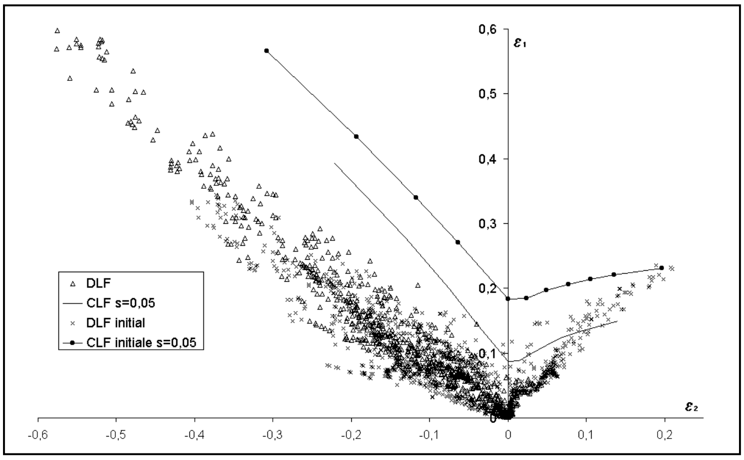

Figure 1. FLD and FLC for the initial and optimal material parameters (iteration 7).

References:
[1] Delamezière A., Naceur H., Batoz J.L., Knopf-Lenoir C., Guo Y.Q., "On the optimum

material properties of thin sheets obtained by deep drawing”, 4th Conference on Material Forming, ESAFORM, Liège, Belgique, Avril 2001, Actes de la conférence, Vol. 1,pp. 317-320
[2] A. Graf, W.F. Hosford, “Calculations of Forming Limit
Diagrams”, *Met. Trans.,* V21A, pp.87-94, (1990)
[3] Brunet S., J.L. Batoz, Bouabdallah S, "Sur l'évaluation des risques de plissement local de pièces industrielles obtenues par emboutissage", Actes du 3eme Colloque National en Calcul des Structures, pp 753-758, Giens, France, (1997)
[4]Hutchinson J.W., Neale K.W., "Wrinkling of curved thin sheet", *International Symposium on plastic Instability*, Paris, France, September 9-13, (1985), pp71-78
[5] Neale K.W., Tugcu P., "A numerical analysis of wrinkle formation tendencies in sheets metals", *Int. J. Num. Meth. Eng*., V30, pp1595-1608, (1990)
[6] Nayroles B., Touzot G., Villon P., Using the diffuse approximation for optimizing the location of anti-sound sources, J. Sound Vibration 171 (1) (1994), 1-21.

7. List of publications

a) Published

BATOZ, J.L., NACEUR, H., DELAMEZIERE, A., GUO, Y.Q., KNOPF-LENOIR, C., «Design of process parameters in deep drawing of sheets to improve manufacturing feasibility», in Integrated Design and Manufacturing in Mechanical Engineering'2000, Chedmail et al., Eds, Kluwer Academic Publishers, 2002, pp 295-302

DELAMÉZIÈRE, A., NACEUR, H., BREITKOPF, P., KNOPF-LENOIR, C., BATOZ, J.L., VILLON, P., «Faisabilité en emboutissage : optimisation du matériau par surface de réponse, Mécanique et Industries, volume 3, Issue 2, 2002, pages 93-98.

b) Submitted for publications

NACEUR H., DELAMÉZIÈRE, A., BATOZ, J.L., GUO, Y.Q., KNOPF-LENOIR, C., « Some improvements on the optimum process design in deep drawing using the Inverse Approach », Journal of Materials Processing Technology, accepté, à paraître 2003.

c) In preparation