COST 526 – Project *F3*
Final Report
Optimization of Process Parameters in Sheet Metal Forming

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1. Introduction

Figure 1 shows a simplified CAD representation of the tools and initial blank in the stamping process. During stamping, the metal sheet is submitted to large displacements and large elasto-plastic strains; rupture and wrinkles must be avoided, (Figures 2 and 3). The resulting part must also satisfy quality requirements regarding its geometry: after tools removing, the springback effect (Figure 4) can produce a non admissible final shape. The definition of the tools (punch, die, blankholders), choice of material (anisotropy, hardening) and process parameters (number of forming stages, forces to apply) must be performed for every new part to manufacture (there are several hundred parts obtained by stamping in a compact car). Improvement of the design and tryout procedures using numerical simulations may have a significant impact on the cost of the tools and on the reduction of the total time from design to manufacture, with also the possibility to provide better solutions than those determined from purely experimental tryout procedures.

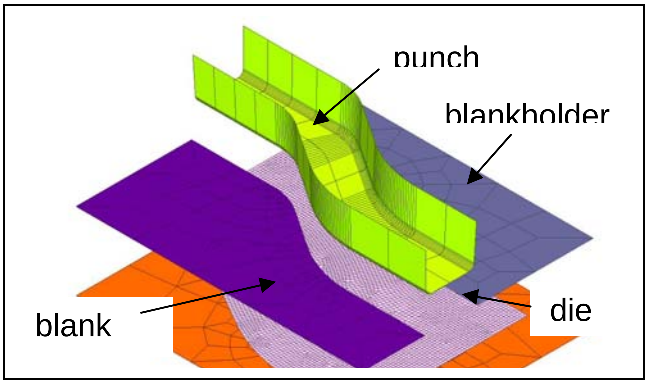

Figure 1: The stamping process

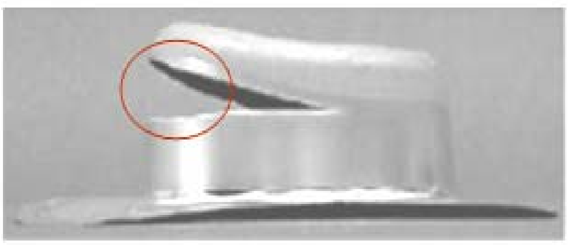

Figure 2: Rupture

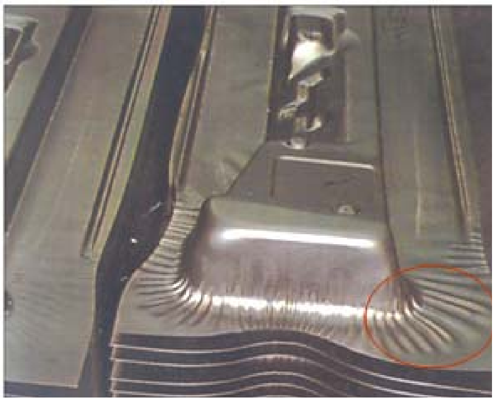

Figure 3: Wrinkling

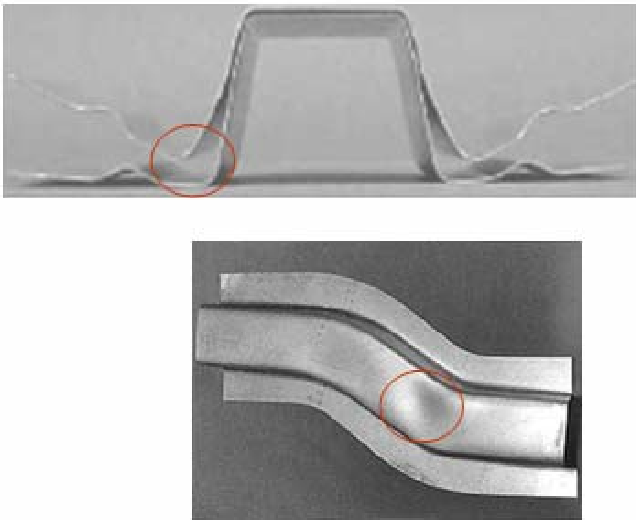

Figure 4 : Springback.

2. Goal of the project

In this project, the final objective is to use simulation and optimization methods to improve the design of tools and the process parameters in sheet metal forming in order to reduce the time to market required to obtain defect-free parts; a second objective is to reduce the production cost by using less material or by saving energy. Several numerical aspects are considered and compared on test problems to evaluate their efficiency and to define optimization strategy for future problems:

- the defects to take into account and their representation by pertinent quality functions,
- the process parameters to optimize
- the simulation code: incremental or simplified approaches
- the optimization algorithms

3. Simulator, calibration, quality function and optimization algorithms, including assessment with respect to alternatives

There are two main categories of numerical solvers for deep drawing simulations. In the first, the strains and stresses in the final part are obtained in a direct (classical) way considering incremental (static implicit or dynamic explicit) approaches [8]. The second category are simplified approaches, also called one-step methods or inverse approaches (I.A.) ([1], [2]). These last methods are efficient and well suited for the preliminary design. The incremental approaches are more precise but involve more computer resources and human skills. They also need a full definition of the geometry and process parameters. In the inverse approach, only the initial flat blank and the final 3D shape of the workpiece are assumed to be known a priori (Figure 5). This method provides rather good estimations of displacements and strains, but less accurate values of the stresses are often obtained. Thus, depending on the requested precision or the type of stamping problem to deal with, the one-step software Fast_stamp [9] or the incremental code ABAQUS explicit have been used as simulation softwares in the optimization loop.

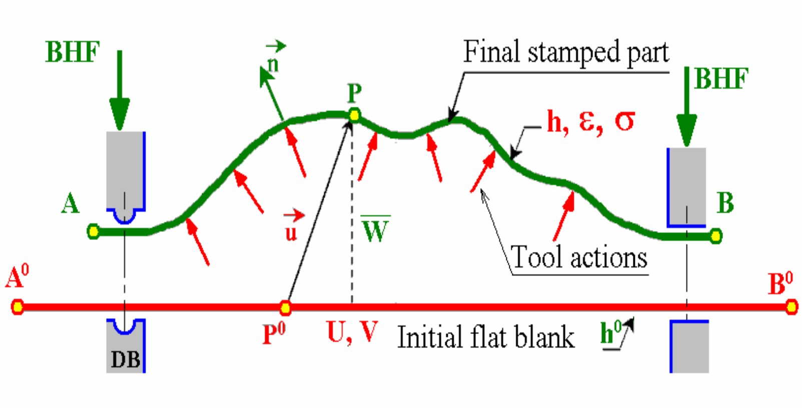

Figure 7: Description of the inverse approach (in green the known quantities, in red the unknown ones).

The quality functions are defined to detect the defects which can occur during stamping, or the energy to save; they are defined as functions to minimize or as constraints, associated to each defect which may occur. The following functions have been considered:

Thinning. Necking. Rupture

There are several ways to detect the risk of rupture in a workpiece:

- a large thickness decrease between the initial and final shape can be taken as an indicator of probable failure; a first objective function J_1 can thus be defined as a norm (domain integral) of the relative thickness variation between initial blank and the final part.

- a second way is to compare the principal strains values, represented in a 2D space, (Forming Limit Diagram, F.L.D.) obtained during the stamping of the part to the Forming Limit Curve, which is a characteristic of the material. The F.L.D. must remain under the FLC. The quality function J_2 represents the violation of a "security limit" under the FLC.

Wrinkling

In a similar way, the risk of wrinkling can be detected by differentl quality functions:

- based on thickness variation
- based on a local wrinkling criterion taking into account the geometry and the stress state ([3], [4])
- when the incremental simulation is performed, a more precise indicator can be expressed, using the amplitude of the wrinkles which may occur.

Springback

The difference between the final shape of the part and the desired shape must be as small as possible. The quality function is a measure of the distance (difference node to node) between the two geometries.

The inverse approach has been modified to improve the springback computation [5, 6]: it consists in taking into account the most important bending-unbending effects due to the material flow over the tool radius. The effects modify the values of the resultant forces without increasing the CPU time. Therefore the global efficiency of the I.A. is kept, however the modifications require a good preliminary geometrical inspection of the part. The method is called Improved I.A. (I2A).The forming analysis stage using the I2A can be followed by an Updated Lagrangian Formulation (ULF) using the same type of DKT12 shell elements with 12 dof per element, but with assumption of small elastoplastic strains (after forming) and taking into account the knowledge of the residual forces at the end of the forming stage as initial conditions.

The above ULF leads to an incremental implicit approach which is very efficient and quite precise for the estimation of the equilibrium and warping displacements due to springback after forming or cutting operations.

The Splitting Ring Benchmark is used to validate the I2A method (Figure 7). Figure 8 shows the results of the circumferential stress distribution on the outer surface using ABAQUS® standard (Implicit) and the I2A method.

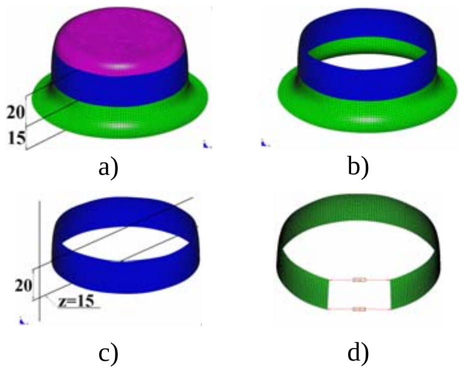

Figure 7. Splitting Ring Benchmark – Main operations

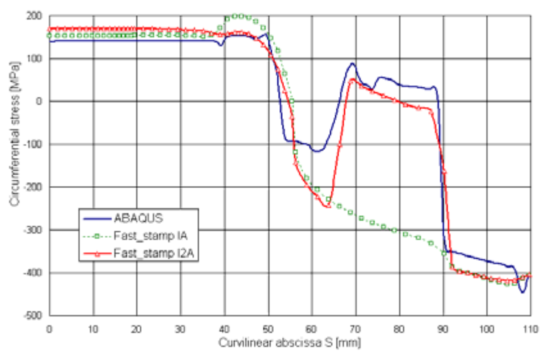

Figure 8. Stress distribution on the top flange- comparison

Energy

The objective function is the external work W_{ex} during stamping, which is directly linked to the energy which consumed by the forming press. This criterion is used in the case of a deformable flexible blankholder, with blankholder forces as design variables [7].

4. Main scientific outcome

Several strategies of simulation methods and minimization procedures have been implemented to study and solve various optimization problems:

- quality criteria have been defined to take into account the risks of necking, rupture and wrinkling, and the springback effect. The physical and mechanical meaning of these criteria are better understood.

- simplified (inverse approach) and incremental (explicit) simulation methods are used, depending on the nonlinear problem considered,

- adaptive response surface strategy appears as an efficient method when the simulation time is very important and the number of design variables is low (≤4). Direct minimization with a SQP algorithm has been applied when gradients are available.

- Optimization results are available for the following examples :

cylindrical cup (Numisheet'02) : optimization of the blankholder forces during punch displacement

square box : optimization of restraining forces, of the material parameters, and design of the initial blank, optimization of the blankholder forces

Twingo dashpot cup : optimization of restraining forces, of the material parameters, and design of the initial blank

U-bending test (Numisheet'93): minimization of the springback effect

Car front door panel (Numisheet'99): optimization of the blankholder force distribution

5. Main technical outcome

An improved version of the simplified Inverse Approach for stamping analysis has been developed and is now integrated in the commercial code Stampack.
Several optimization strategies have been used to solve problems having from 2 to 16 design variables, with one-step and with incremental simulations. These test problems can give indications to choose the right strategy for new situations.

6. Collaboration within COST 526

Collaboration with University of Liège (on shell modelling and optimization techniques), with ENSAM Angers (F) and other partners of OPTIMAT RNTL project.

7. Cooperation with industry

Mecalog, France : optimization algorithms
Quantech, Spain : improvement of the One step code for stamping

8. References

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