

COST 526
Automatic Process Optimization in Materials Technology
(APOMAT)

Title:

Optimization of sheet-metal blanking and bending-processes: Application to the forming of High Strength Steel security parts

Keywords :

Sheet-Metal, blanking, bending processes ; elastic springback; parametric optimization ; damage laws ; finite element method, mechanical parameters identification

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1. Duration/run time of the project

The project will run from October 2001 to December 2004.

2. Overall cost

The overall cost for each academic partner would be 0.15 million Euros

3. Funding situation

France : to be mentioned later

Northern Ireland : to be mentioned later

Belgium : KULeuven : Funding applied for at the DWTC (Belgian Federal Office for Scientific, Technical and Cultural Affairs)

4. Project partners indicated to participate

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5. Project partners to be found

I- Academic collaborations with research teams in Europe : the objective would be to enhanced the comprehension of the blanking and bending processes, to share experiences in both part and to establish graduate and post-graduate students exchanges. Efficient research teams in the field of mathematical optimization would be greatly associated with the aforementioned partners.

II- Industrial collaboration with european companies : the objective would be to extracts from the industrial operations the state-of-the-art. Then testing devices including industrial constraints would be made with the aid of industry, in order to validate the simulation results.

6. Short description of the material process

The bending process deals with sheet-metal forming of small or medium sizes mechanical-parts, widely used in automotive or aerospace industries. The sheet-metal (isotropic or more generally anisotropic) is priorily shaped by blanking and then bent into a die by means of a punch. The overall geometry of the final part depends on the elastic springback phenomenon which needs an accurate prediction. During the forming process, the material undergoes damage which influence the strength and the fatigue life of the parts. As the parts are mainly used as safe-life parts, an efficient numerical simulation will takes into account the aforementioned phenomenon providing an accurate prediction of the behaviour of the structural elements. So the part's quality after the bending operation will be accurately predicted in terms of strength and geometry leading to a strong economical impact knowing that this industrial process provides millions parts a year in leading car and aerospace companies.

7. Material(s) involved

Laminated sheet-steel

High Strength Steel (HSL)

TRIP Steel, IF Steel

(Sub-micron) Aluminum alloys

8. Optimization potential of the process or the process step

The objective functions to be defined will include the damage supported by the material :

- in the blanked face for the blanking process

- in the bent area for bending process

and the residual stress field in both case.

The parametric optimization concerns first the knowledge of the material behaviour wich is delivered in the form of large laminated strips undergoing many rolling up operations, the sheet-thickness evolution and the geometrical parameters of the die and the punch.

The constraints imposed on the process are related to :

I- the forming limitations i.e :

- blanking or bending forces of the press machine

- the wear of the tools

- the metal sheet texture
- no cracks, no necking and wrinkling zones
- zero residual springback (by counterbalancing).

II- The mechanical resistance of the formed parts subjected to loads.

The optimization potential of the process will be achieved through :

- geometrical and technological rules to be respected.
- in process data characterization of optimum life cycle of the tools.

9. Specific material properties to be achieved

The main material properties occurring in the optimization process are the Young modulus $E(\bar{\epsilon}_p)$, the Poisson ratio, the anisotropic coefficient r , the damage identification and evolution laws $D(\bar{\epsilon}_p)$ and the hardening law $\sigma_0(\bar{\epsilon}_p)$, as functions of the plastic strain parameter $\bar{\epsilon}_p$. It has been recently discovered that the final behavior of the parts were strongly dependant on the form of the inclusion appearing in the material so, the metallurgical analysis would be a great part of the material characterization. The defects to be avoided or minimized, are the residual stress field, a too large damaged area during blanking and bending, the cracks or necking at the corner outside and the wrinkling at the corner inside of the bent parts.

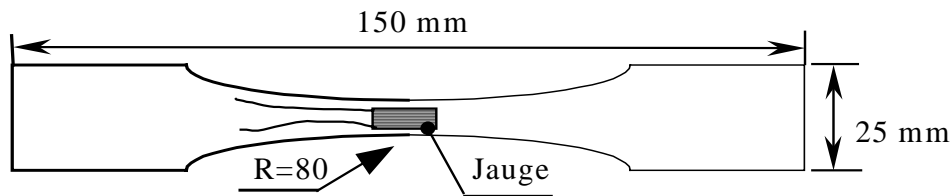


Figure 1 : tensile specimen with electric gauge for the damage characterization

10. Process parameters to be optimized

Knowing that the quality of blanked or bent parts is associated with its accurate shape (, no oval-shaped holes due to anisotropy, no uncontrolled springback effects) and its ability to support working forces after bending, the process parameters are related to :

- a- the material sheet : i.e its physical and mechanical properties as defined in 4 offering the best capabilities,
- b- the industrial process i.e
 - the geometry of the tools (die and punch radius, bending angle),
 - the operating conditions (blank holder clamping forces, friction coefficient and lubrication),
 - the speed of the operation,
 - the tool life related to the wear of the punch and the die (inducing possible geometric variations between parts formed at the beginning or the end of the tool life)

Upon these parameters which are the design variables, geometrical, mechanical and technological constraints are imposed.

11. Material laws including material dependant coefficient

The material involved in the bending process to be optimized in the proposal, is mainly steel and specially High Strength Limit steel but aluminum alloys can also be included in the study. The material constitutive laws are still to be accurately defined that is :

- 1- the metallurgical aspects (grain sizes, distribution of micro-defects, chemical composition)

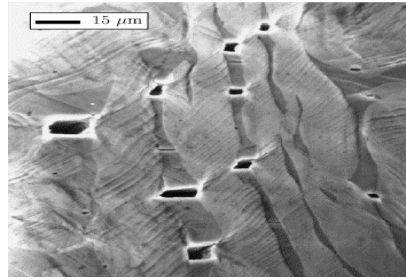


Figure 2: micro-defects distribution in a material, inducing a probability of damaging effects.

- 2- the damage law and its evolution during the process,
- 3- the Bauschinger effect which modifies the behaviour law in tension or compression and has a great influence on the final behaviour of the part.
- 4- eventually the relation between macro analysis of damage and micro-analysis of the material.

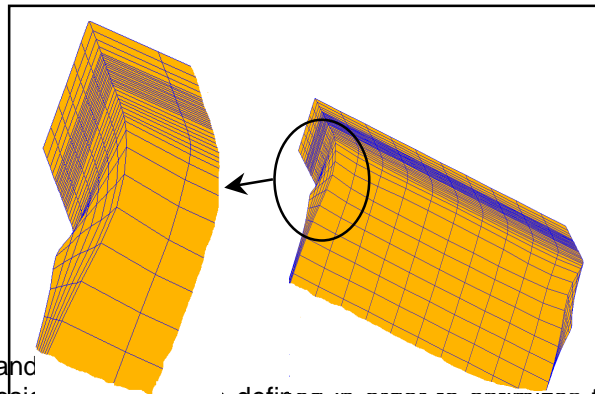


Figure 3 : bending simulation and The related quality-function design : defined in order to optimizes the bending process. The main objective is to minimize the material damage occurring during the industrial operations of blanking and bending. Concerning the blanking process, many characteristic functions have been carried out during previous works allowing for analytical formulation closed related to the numerical studies. In such situations it would be easy to optimize the process by means of mathematical optimization software. Concerning the behavior of the security parts, the objective function is related to the shock-proof when a tensile force unbend the part clamped on a vehicle.

12. Simulator

The software to be applied during the optimization process are incremental explicit finite element codes as ABAQUS or PAMSTAMP and FORGE3 and LAGAMINE.

We have developed many user's subroutine in ABAQUS Standard (see references) for the simulation of blanking and bending including the damage influence. The previous studies on blanking allowed us to propose some analytical formulas concerning the prediction of the punching force, the burr zone in the blanked surface and the wear resulting from the press operation. An in-house software called Blanksoft has been developed and implemented in supporting company. It allows for the determination of the process characterization and the part geometry prediction. An inverse approach can be developed in order to identify the forming in-process.

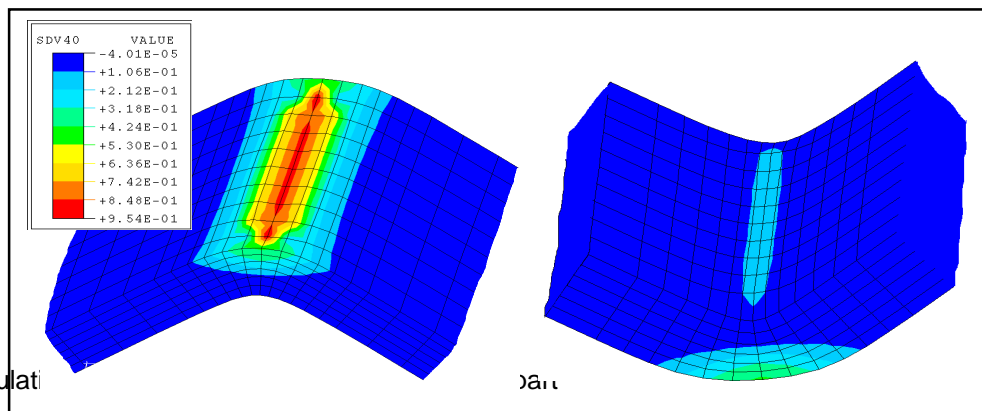


Figure 4 :Simulation

13. Optimizer

Optimization will be run with NAG software including linear and non-linear algorithms and in-house Mathematical Programming as Genetic Algorithms and Taguchi methods. Sensitivity analysis will provide the basis for determining the most effective optimisation strategies. The new academic partner will be able to develop design experiments studies related to the experimental data resulting from industry and laboratory, and numerical values predicted by the numerical simulation. Bayesian technics for optimization would provide useful tools in order to achieved the process optimization. The constraints imposed on the process concern the material parameters to be considered in physical and numerical modelling of :

Blanking process :

- Texture of the steel sheet,
- Sheet thickness variation,
- Hardness of the sheet
- Anisotropy of the material
- Work hardening
- Stress –strain relationship
- The Bauschinger effect

Tooling parameters to be considered in physical and numerical modelling of blanking process:

- Tool geometry(cutting edge radius)^{1,2}
- Tool velocity
- Clearance between punch and die
- Tool stiffness
- Friction

It is reported that actual force-displacement values for blanking differs considerably from those obtained by tensile test method. Hence the force displacement values for blanking will be obtained through in-process data characterization and stress-strain relationship to aid the numerical model will be established by analytical means.

Bending process

- Texture of the steel sheet,
- Sheet thickness variation,
- Grain orientation
- Anisotropy of the material
- Work hardening
- Stress –strain relationship
- The Bauschinger effect

Tooling parameters to be considered in physical and numerical modelling of blanking process:

- Punch geometry
- Tool penetration
- Die geometry
- Tool velocity
- Tool stiffness
- Friction

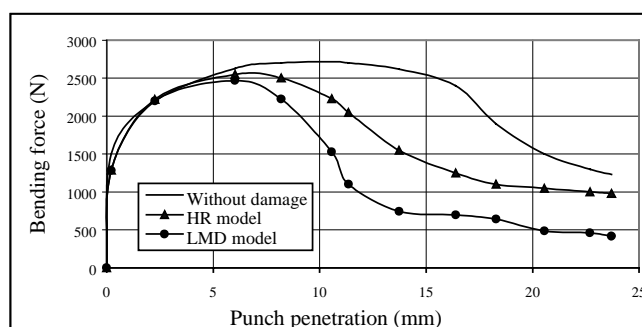


Figure : Comparison between damage models resulting from ABAQUS simulation

14. Competence/Activities of proposer

We are working on the subject of sheet-metal process from ten years ago. The subject of this proposal is in a faisability stage in our research team since one year ago. our activity is strongly related with industry and numerous contracts

We are highly specialized in numerical simulation in sheet-metal process, in testing devices for which in various fields we have developped machines for mechanical material-characterization.

The french research teams include two Professors, five Associate Professors, a PhD student starting his work on the bending process one year ago, a post graduate DEA student and two technicians.

We dispose of two presses (4000 KN and 100 KN) with instrumentation and data acquisition, a microhardness device, a residual-stress analysis device , an Instron fatigue machine for tension and compression and it's piloting computer and related data acquisition devices, several machine tools and confirmed operators.

The simulation will run on PCs and Indy and Octane station computers.

15. International State of the art and references

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