EUROPEAN COOPERATION IN THE FIELD OF SCIENTIFIC AND TECHNICAL RESEARCH - COST

COST 526
Automatic Process Optimization in Materials Technology
(APOMAT)

Title:

Forging Process Optimisation

Keywords: forging, metal forming, finite elements, optimisation algorithms, sensitivity analysis, folding defects, metallurgy, steel, aeronautical alloys

Organisation/Company:
CEMEF, Ecole des Mines de Paris
Rue Claude Daunesse
BP 207
06 904 Sophia Antipolis Cedex
France

Project leader: **Lionel Fourment**
Tel.: **+33 4 93 95 75 95**
Fax: **+33 4 93 65 43 04**
E-mail: **fourment@cemef.fr**

1. Duration / run time of the project

4 years, starting at the beginning of the APOMAT project and running until its end.

2. Overall cost

150 kEURO

3. Funding situation

Thinking about funding by industrial company

4. Project partners indicated to participate

Several French national forging companies and software house belonging to the “SIMULFORGE” project.

The industrial partners will precisely define the forging problem to be studied. They will carry out a “sensitivity analysis” by varying the forging conditions of some test problems. These “experimental” variations will be compared to the computed ones. Finally, some industrial forging problems will be considered for optimisation using automatic numerical optimisation. Optimised designs will be evaluated by forging experts and possibly industrially tested.

This collaboration will provide a profound validation of the numerical approach. For the industrial partners, it will improve their understanding of the complex 3D forging phenomena and provide better designs for some test cases. Possibly, it will change their design methodology.

5. Project partners to be found

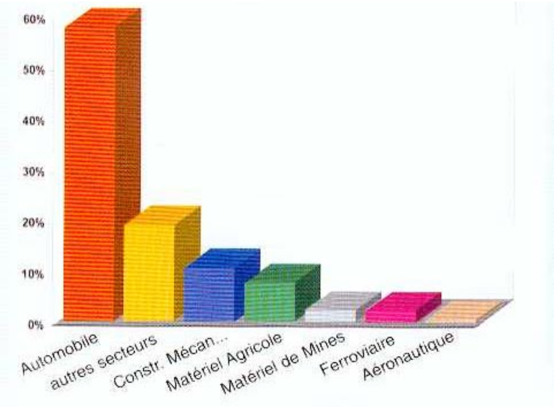
none

6. Short description of the material process to be optimised

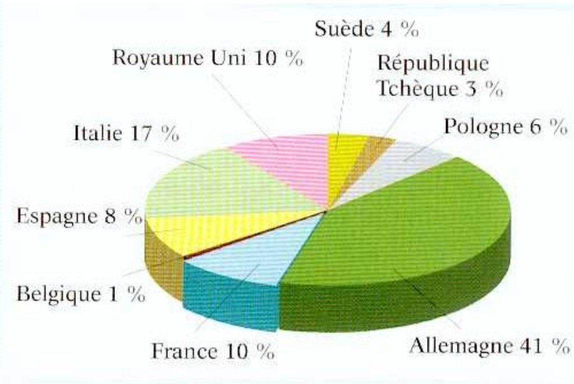
We study the industrial hot forging process, while our approach is more general and can easily be extended to other metal forming processes, such as reverse super-plastic blowing of metal sheets.

The process consists in several operations. The initial workpiece, very often a cylinder or a simple geometric part, is heated and then forged between the dies of a press. The shape of the dies has the female shape of the part to be formed. This provides the first preform. Generally, this preform is forged again to produce a finer prefrom, which shape is closer to the final one. After several forging operations, the final part is obtained. The conditions of each operation - temperature, forging velocity, forging distance, die shapes - are very important to obtain proper material flows and satisfactory metallurgical qualities in the end.

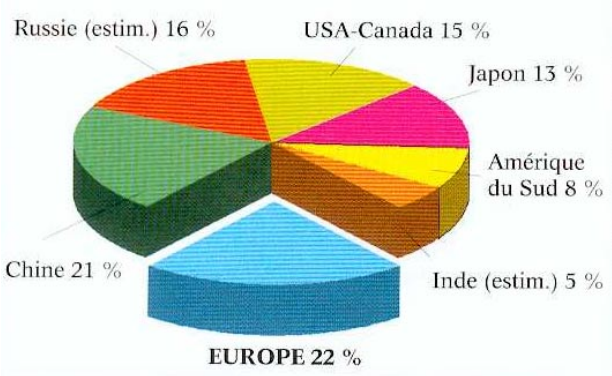
Forging regards both mass production and the making of unit parts. It also regards both simple and very complex shapes, with simple or very severe metallurgical requirements. It has a very large impact on the car and plane industry, and on lot of other areas. The European hot forging production is around 2 500 000 tons. In France, in 1999, it represented a turn-over of 8.3 billion of French Francs.



markets of the European forging industry



distribution of the forging activity in Europe



distribution of the forging activity in the world

7. Material(s) involved:

Steel and aeronautical alloys such as Inconel or Titanium alloys.

8. Optimisation potential of the process or process step

Optimisation of complex industrial forging sequences – avoid expensive trials – reduce by 30% the cost of the dies.

Automatic design of preforming tools – provides new designing routes

Improvement of metallurgical qualities of forged parts – allows improving the present forming sequences but also managing several optimisation criteria (which experts find difficult to do)

More stable forming sequences (less subject to small process perturbations) – reduction of tool wear, so improving their life up to 100%

Reduction of designing time – less trials, improved knowledge of the process

Reduction of material consumption (less trials, less material for the sequence) – very significant in the aeronautic industry – 20% of material reduction expected

Solving several industrial axisymmetric problems has already showed feasibility of such optimisations.

9. Specified material properties to be achieved

Prescribed grain size distribution (maximal admissible value)

More homogeneous distribution of the cumulated strains

Minimal shear stress value inside the material

No surface defects, such as fold-over

No piping defects resulting in not producing the required shape

10. Process parameters to be optimised

Forging velocity – according to the potential of the press, which also depends on the type of the press - forging height

Forging temperature (of workpiece and tools) – inside the limits of hot forging conditions and sufficient resistance of the dies.

Lubrication conditions

Shapes of the preforms – lot of freedom for design

Position of the workpiece inside the tools

11. Material laws including material dependent coefficients

Visco-plastic laws, thermo-elasto-viscoplastic laws

Strain hardening and temperature softening

Grain size evolution

The coefficients of these laws are most of the time available. This is another reason for collaborating with industry. For complex metallurgical evolution, approximated models are very often used and satisfactory – for a first approach.

No need for additional determination of these coefficients.

12. Simulator

FORGE2® and FORGE3® are dedicated finite element packages for the numerical simulation of metal forming processes (and forging, more particularly). They are based on a P1+P1 finite element method, with a mixed velocity-pressure formulation, that is solved iteratively. Automatic meshing and remeshing allows handling the large element deformations. A mesh partitioning technique allows parallel resolution.

Some small enhancements to the software are required for the project, such as computing process objective functions – measurement of the non-quality of the design.

13. Optimiser

BFGS type optimisation algorithms will be used – internally developed

Constrained algorithms – internally developed or studied using free-access packages

Computation of gradients by analytical or semi-analytical methods

14. Competence / activities of proposer

CEMEF is a well-known research laboratory focused on the numerical simulation of metal forming processes. Since 1981, it has been working on the numerical simulation of forging. It has resulted on the marketing of the FORGE2® and FORGE3® software. Forging simulation still drives a significant research activity. On the other hand, we have been working more specifically on forging optimisation since 1992. In the frame of national and European projects, software SAFO has been derived. It allows optimising the axisymmetric forging preforms.

ENSMP-CEMEF (Centre de Mise en Forme des Matériaux - Centre for Materials Processing) is a strong research centre devoted to the physics, chemical physics and mechanics of materials processing. Approximately 130 people – including 50 PhD students – study the basic science of processing many different types of materials: metal, polymers, composites, foodstuff materials, etc. One of the activities of ENSMP-CEMEF, started around 1980 and steadily developing ever since, is the creation of several finite element software devoted to materials forming Research & Development, industrialised and commercialised by TRANSVALOR. Forge2® (for 2D, axisymmetric pieces) and Forge3® (for complex 3D pieces) - software now being used in more than 50 companies in Europe - have reached a high degree of achievement and some commercial success.

15. International state of the art and references

On this topic, most of the authors are nowadays following the same approach. It is based on the simulation of the different process operations by the finite element method, the computation of objective functions, and on optimisation methods using BGFS type algorithms. The gradients are calculated by a direct differentiation method of the discrete problem.

Main references on the subject:

(Park, Rebelo et al. 1983; Kusiak and Thompson 1989; Badrinarayanan and Zabaras 1996; Zhao, Huff et al. 1997; Chung and Hwang 1998; Rodiz 1999)

Our references:

(Fourment and Chenot 1994; Fourment, Balan et al. 1995; Fourment, Balan et al. 1995; Chenot, Massoni et al. 1996; Fourment, Balan et al. 1996; Fourment, Balan et al. 1996; Fourment, Vieilledent et al. 1997; Vieilledent, Fourment et al. 1998; Fourment and Vieilledent 1999; Fourment and Chenot 2000; Fourment and Vieilledent 2000; Fourment and Vieilledent 2000; Vieilledent and Fourment 2001)

List of references:

Badrinarayanan, S. and N. Zabaras (1996). “Sensitivity analysis for the optimal design of forming processes.” Comp. Meth. Appl. Mech. Eng. **129**(February, n°4): 319-348.

Chenot, J.-L., E. Massoni, et al. (1996). “Inverse problems in finite element simulation of metal forming processes.” Engineering Computations **13**(2/3/4): 190-225.

Chung, S. H. and S. M. Hwang (1998). “Optimal process design in non-isothermal non-steady metal forming by the finite element method.” Int. J. Num. Meth. Eng. **42**: 1343-1390.

Fourment, L., T. Balan, et al. (1995). Shape optimal design in forging. Shape optimal design in forging, Ithaca, New York, Balkema, Rotterdam.

Fourment, L., T. Balan, et al. (1995). Shape optimization for the forging process. Computational Plasticity - Fundamental and Applications, Barcelona, Pineridge Press, Swansea, UK.

Fourment, L., T. Balan, et al. (1996). “Optimal design for non steady-state metal forming processes-

I Shape optimization method- II Application of shape optimization in forging." International Journal for Numerical Methods in Engineering **39**(1): 33-66.
Fourment, L., T. Balan, et al. (1996). Shape optimization of the preforming tools in forging. International Conference on Inverse Problems in Engineering : theory and practice, Le Croisic, France, The American Society of Mechanical Engineers, New York.
Fourment, L. and J.-L. Chenot (1994). The inverse problem of design in forging. Inverse Problems in Engineering Mechanics, Balkema, Rotterdam**:** 21-28.
Fourment, L. and J.-L. Chenot (2000). Inverse methods applied to metal forming processes. Engineering Computational Technology conference, Leuven, Saxe-Coburg Publications, Edinburg.
Fourment, L. and D. Vieilledent (1999). Computer aided preforming tool shape design in hot forging. 6th International Conference on the Technology of Plasticity, Nuremberg, Germany.
Fourment, L. and D. Vieilledent (2000). Metallurgical Qualities Improvement by automatic preform design of forging processes. Conference on Metal Forming, Krakow, Poland, Balkema, A. A. / Rotterdam / Brookfield.
Fourment, L. and D. Vieilledent (2000). Shape optimisation for metal forging problems : determination of an objective function for flow defects. European Congree on Computational Methods in Applied Sciences and Engineering, Barcelona.
Fourment, L., D. Vieilledent, et al. (1997). Automatic design of tools in forging. NAFEMS World Congress'97, Stuttgart.
Kusiak, J. and E. G. Thompson (1989). Optimization techniques for extrusion die shape design. Numerical Method in Industrial Forming Processes, alkema / Rotterdam / Boston.
Park, J. J., N. Rebelo, et al. (1983). "A new approach to preform design in metal forming with the finite element method." International Journal Tool Design Research **23**(n°1): 71-79.
Rodiz, T. (1999). Optimisation of prestressing of cold forging die by using symbolic templates. European Conference on Computational Mechanics, München, Germany, CDrom.
Vieilledent, D. and L. Fourment (2001). "Shape optimization of axisymmetric preform tools in forging using a direct differentiation method." to appear in International Journal for Numerical Methods in Engineering.
Vieilledent, D., L. Fourment, et al. (1998). Toward an automatic preform design software for axisymmetrical forging. 2nd Int. Conf. on Integrated Design and Manufacturing in Mechanical Engineering, U.T.C. Compiègne.
Zhao, G., R. Huff, et al. (1997). "Sensitivity analysis based preform die shape design using the finite element method." J. Materials Engineering and Performance **6**: 303-310.