Methodology of the shape optimization of forging dies

Fanjuan Meng, Carl Labergere, Pascal Lafon

Methodology of the shape optimization of forging dies

Fanjuan MENG[1*], Carl LABERGERE[1], Pascal LAFON[1]

[1]University of Technology of Troyes
Institut Charles Delaunay – LASMIS FRE CNRS 2848
Phone: 0033325759723 Fax: 0033325715675 E-mail : fanjuan.meng@utt.fr

ABSTRACT: In forging process, the dies shape design is the most important step. Reasonable dies shape can not only reduce raw material cost but also improving product quality. Currently there are no packages for the forging process with both simulation and optimization capabilities. So in our research, the main objective is to use the simulation of forging process coupled with an optimization procedure in order to obtain the optimal parameters of the geometry of the dies.
To develop this forging process optimization system several numerical tools are required: geometric modelling (CATIA V5™), FE analysis (ABAQUS®), and optimization computation. In this paper, the basic methodology of the forging dies shape optimization method is introduced.
In addition to that, with the proposed 2D FE model, we simulated the platting and the forging operation of an industrial example with a hammer machine. The total energy for each simulation is the same. But for applying the energy, we use different number of blows. By doing this test, we can evaluate the influence of the number of blows on the energy dissipation and get more knowledge on the formulation of future optimization problem.

KEYWORDS: Forging; Numerical Simulation; Optimization; the number of blows; Energy dissipation

1 INTRODUCTION

Nowadays, in forging process the numerical simulation is used to avoid long and expensive experiments and many research works have been made in this aspect [1]. Besides this, the optimization of the geometry of the forging dies is another focus point during the recent years in order to minimize the forging energy, minimize the cost and obtain the desired part with good metallurgical quality.

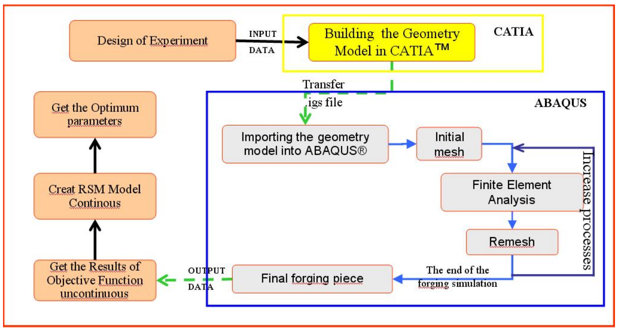

Figure1: *The whole simulation and optimization model*

The whole simulation and optimization model is shown in Figure 1. We use the CAO software CATIA V5™ to create the geometry of the dies and define the shape parameters that we want to optimizer. Then, we input the shape and parameters into a software package based on ABAQUS® to simulate the forging process. By changing the values of the parameters, we can get a set of discontinuous results. Then, establishing the response surface model, the advanced optimization algorithms will be performed to reach the optimum for variables.

2 ESTABLISHMENT OF 2D FE MODEL OF FORGING PROCESS

In the Mechanical System and Concurrent Engineering Laboratory (ICD-LASMIS), an extensive work has been developed since ten years. A finite element package has been developed to solve thermo-visco-elasto-plastic problems with ductile damage in large deformation. This package allows realizing automatically numerical simulation of metal forming processes. And in order to achieve properly the convergence of calculation, meshing and remeshing procedure are also included [2-4].

2.1 THERMO-VISCO-ELASTO-PLASTIC BEHAVIOUR MODEL

To build the behaviour material model, the simulation of forging operation imposed different multi-physic coupling (temperature, plastic strain, and rate plastic strain). In this work we used an advanced constitutive equations accounting for non linear isotropic and kinematic hardenings strongly coupled with ductile isotropic damage. The coupling between the ductile

* Corresponding author: postal address, phone, fax, email address

damage and the elasto-visco-plastic constitutive equations is formulated in the framework of the thermodynamics of irreversible processes together with the Continuum Damage Mechanics (CDM) theory [3-5].

2.2 NUMERICAL ASPECT

The fully coupled thermomechanical constitutive equations presented above have been implemented into Abaqus/Explicit FE code using the Vumat user subroutine. The dynamic explicit resolution procedure has been used in order to solve the thermomechanical problem based on both weak forms relative to the equilibrium and thermal equations. Due to the large deformations of the material, the mesh is rapidly distorted. To avoid large mesh distortions, the mesh must be adapted. By using the adaptive remeshing technique in our laboratory, numerical simulations of various metal forming problems have been down and proved its efficiency [2, 3].

3 ESTABLISHMENT OF THE OPTIMIZATION PROBLEM

A complete simulation design is conducted in an iterative process with different values of parameters. In order to obtain an acceptable time of calculation, simulation are driven in parallel, on several multiprocessor blade calculators [6]. And after the simulation is finished, the optimization program is called to get the optimum parameters of the forging dies.

According to the industrial requirements, the geometrical parameters of the forging dies (such as fillet radius, draft angle, flash design, machining allowance, etc) and the initial dimension of the cylindrical piece are served as the variables to be optimized.

Different objective function can be used to verify different criteria. The one criterion is the minimization of the initial volume of the billet. Because the most important driving force in a manufacturing process is to produce the best product at the lowest cost [7]. The second consist in minimizing the strain energy. The strain energy represents the total strain energy used during the forging process in order to deform the billet to obtain the desired form. So from an economic point of view, it is important to minimize it. The third important criterion is to improve the metallurgic quality of forged part.

So the objective functions can be summarized as:

$$Min \quad V_T = \pi R_0^{\ 2} H_0$$

$$E_T = E_{platting} + E_{forging}$$

$$Min \quad = \int_0^{t_1} \int_{V_{platting}} \left(\sigma^c : \dot{\varepsilon}_1 . dV \right) dt_1 + \int_0^{t_2} \int_{V_{forging}} \left(\sigma^c : \dot{\varepsilon}_2 . dV \right) dt_2$$

$$Min \quad \sum_{i=1}^{Nb_{ele}} \frac{V_i}{V_T} \left(p_i - p_{ref} \right)$$

Where R_0 is the radius; H_0 is the height of the billet; σ^c is the Cauchy stress matrix; $\dot{\varepsilon}$ is the total (elastic and plastic) strain rate; Vi is the volume of element i; p_i is the equivalent plastic strain computed at the unique Gauss point of the element i; p_{ref} is the reference equivalent plastic strain.

The response surface methodology will be used to model the relationships between the objective functions and the variables. Then, different metamodels based on a polynomial approximation (MLS) or neural network can be used.

4 APPLICATIONS

Using the proposed 2D FE model, we make a series of simulations to evaluate how the number of blows influences on the total energy during the platting and forging process.

A hammer, delivering intermittent blows to the section to be forged, applies the pressure. The mass of the hammer is 6550KG. For each process, we assumed that the total energy is 100KJ. But when the number of blows changed, the total energy is allocated to each blow following Table.1.

Table 1: *The distribution of the energy for each blow*

	Total energy	Each blow
One blow	100KJ	100KJ
Two blows	100KJ	50+50KJ
Three blows	100KJ	30+30+40KJ

4.1 PLATTING PROCESS

For the platting process, the initial cylinder billet measures 209mm (height) by 65mm (radius). The material corresponds to 42CrMo4 steel. The initial temperature of the billet is 1300°C and for one blow the initial speed of the upper die is 5526 mm/s. Figure 2 shows the final shape of the billet after platting and some boundary and contract conditions are also been marked.

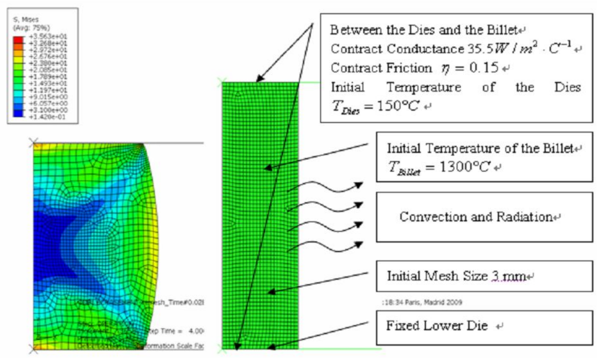

Figure 2: *Final shape of the billet after platting process*

Figure 3 shows the relationship between the displacement and the speed of the upper die by different number of blows. At the beginning of the platting, the initial speed of the upper die is different, it's because the energy for each blow is different. With the increasing of the displacement, the value of the speed decreases gradually. At the end of each blow, the speed is almost zero. It's reasonable theoretically.

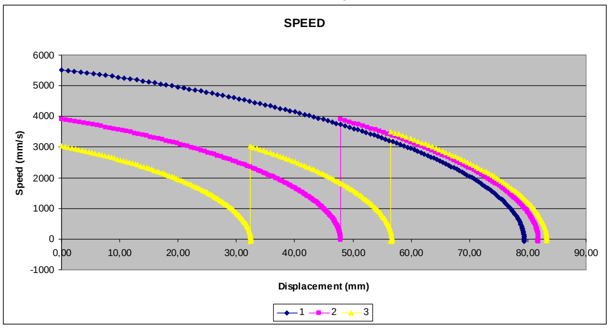

Figure 3: *Speed curves of the different number of blows*

Figure 4 shows the relationship between the force and the displacement. It can be seen that the force increase when the upper die contract with the billet and after one blow the force decrease to zero immediately. It also can be seen that the maximum force of each simulation (for different number of blows) is almost the same. So we can conclude that increasing the number of blows can't affect the force of the upper die dramatically.

Another important point that we can concluded from the figure 4 is that the displacement of the upper die along the axis became larger when the number of blows increases. That is to say, by applying the same total energy, we can get larger deformation of the billet by increasing the number of blows.

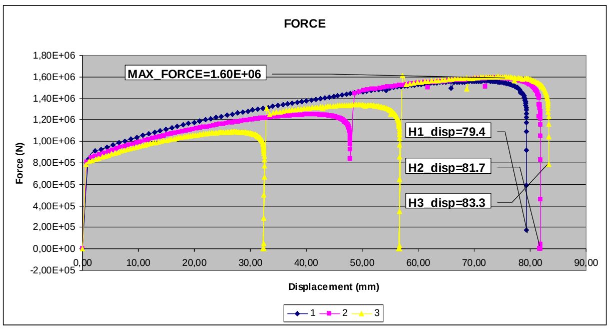

Figure 4: *Force curves of the different number of blows*

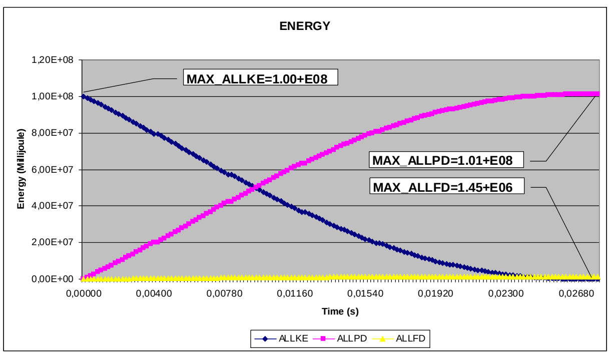

Figure 5: *The comparison between different energy*

The relationship between the different energy can be seen form the Figure 5. It shows that by using hammer, for one blow the kinetic energy decreases to zero. And most of the kinetic energy converts to the plastic dissipation (ALLPD) which is used to complete the shape deformation. And a small part of the energy converts to the friction dissipation (ALLFD) which is wasted and maybe leads to the dies over heating. It is obvious that the optimization aims to increase ALLPD and decrease ALLFD.

Figure 6 shows the relationship between the time and the ALLPD; Figure 7 shows the relationship between the time and the ALLFD. It can be seen that the ALLPD almost the same for each simulation. But the ALLFD isn't same and the more the number of blows the lower the ALLFD. And as a general rule, the value of ALLFD is the smaller the better.

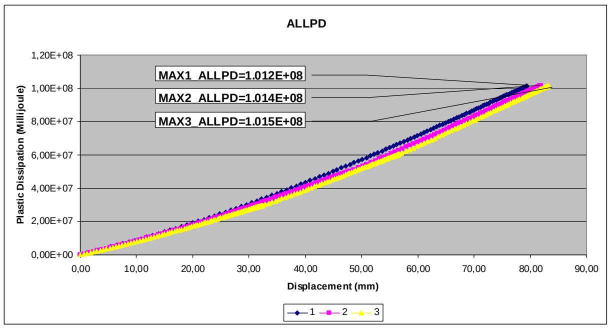

Figure 6: *History of the Plastic dissipation*

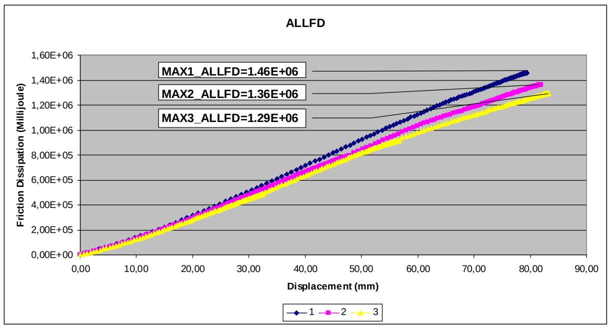

Figure 7: *History of the friction dissipation*

4.2 FORGING PROCESS

The shape of the forging dies is more complicated than the platting process.

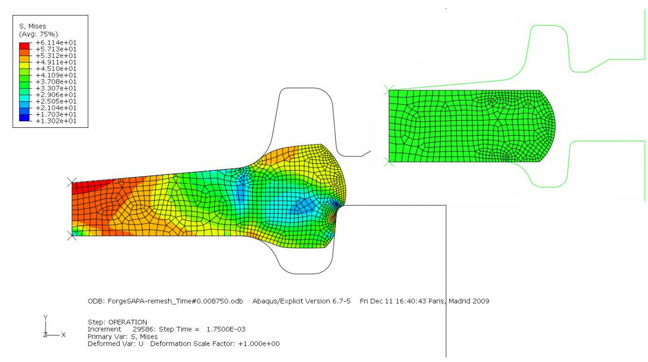

Figure 8: *The final shape after the forging process*

The final shape of the forging process is shown in the Figure 8.

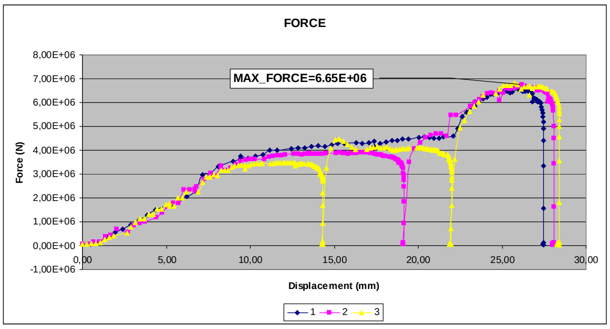

Figure 9: *Force curves of the different number of blows*

Seen from the figure 9, the maximum value of the force of the forging process is lager than the platting process, especially, the force around the displacement of 25mm is quite larger. This is because during the forging process, the billet is contracted with the corner of the lower die. So the force grows up suddenly.

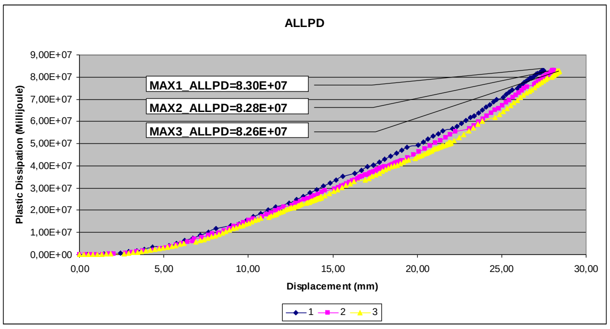

Figure 10: *History of the Plastic dissipation*

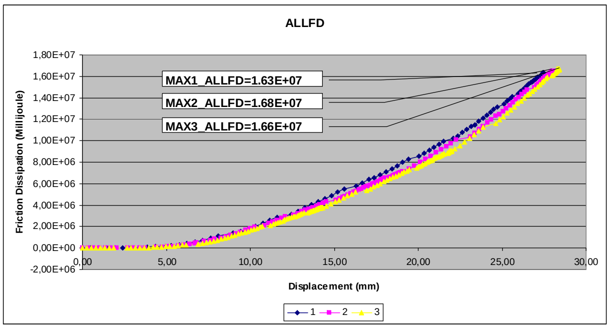

Figure 11: *History of the Friction dissipation*

The history of the plastic dissipation and the friction dissipation of the forging process is shown in Figure 10 and Figure 11. Almost the same results were got with the platting process.

5 CONCLUSIONS

It is concluded that (1) the methodology of the shape optimization model of forging dies is introduced; (2) an 2D simulation design highlights the influence of the number of blows on the different kinds of energy and all results that we get agree with the forging practice and theories, so, the simulation is proved to be useful and has some reference value and guiding significance; (3) the research results of the energy dissipation during the platting and the forging processes help to design the objective function of the optimization model.

In the future, it is desired that the paralleled calculation of the forging simulation will be carried out. Then the optimization process model can be implemented by using the response surface model and some advanced mathematical methods.

ACKNOWLEDGEMENT

This study was supported by the Mechanical System and Concurrent Engineering Laboratory of University of Technology of Troyes and conseil régional de Champagne Ardenne, FRANCE, which are gratefully acknowledged.

REFERENCES

[1] Y.T.Im. A computer-aided-design system for forming processes. Journal of Materials Processing Technology 89-90:1-7, 1999.

[2] C. Labergere, A. Rassineux, K. Saanouni. Improving numerical simulation of metal forming processes using adaptive remeshing technique.*ESAFORM 2008*, pages 23-25, 2008.

[3] C. Labergere, P. Lestriez, K. saanouni. Numerical design of extrusion process using finite thermo elastoviscoplasticity with damage. Prediction of chevron shaped cracks, Key Engineering Materials, Vol 424, pages 265-272, 2010

[4] K. Saanouni, J.-L. Chaboche. Application to Metal Forming, Computational Damage Mechanics, Numerical and Computational methods. in Comprehencive Structural Integrity, Edited by I. Milne, R.O. Ritchie and B. Karihaloo, Vol 3, 2003

[5] P. Lestriez, K. Saanouni, J.F. Mariage and A. Cherouat, Numerical prediction of damage in metal forming process including thermal effects, Int. J. of Damage Mechanics, Vol. 13, N°1, pages 59-80, 2004

[6] I. Khoury, L. Giraud-Moreau, P. Lafon, C. Labergére: Towards an optimisation of forging processes using geometric parameters. Journal of Materials Processing Technology, Vol. 177: pages 224-227, 2006.

[7] D. Vieilledent, "Optimisation des Outils en Forgeage à Chaud par Simulation Éléments Finis et Méthode Inverse Applications à des Problèmes Industriels", Ph.D. Thesis, Ecole Nationale Supérieure Des Mines De Paris, France, 1999.

[8] I. Khoury, P. Lafon, L. Giraud-Moreau, L. DANIEL: Towards an Optimization methodology of a Rough Forged Part taking into account Ductile Damage. In *7th IDMME* ,CHINA, 2008.