COST AND CYCLES REDUCTION BASED ON MANUFACTURING PROCESS SIMULATION

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Abstract

The manufacturing process simulation, by helping to better understand the process, exploring different parameters and determining the tooling design, is a tool to shorten manufacturing development cycles and reduce costs. Keys for successful simulations are given. Industrial examples illustrate the advantages brought by process simulation within EADS group.

1 General Introduction

The manufacturing of industrial components often requires many mechanical and/or thermal operations in order to satisfy the requirements. The first of these requirements - obtaining a correct geometry – may be really challenging at the development stage, especially when dealing with a new process. Though the reasons for this may be diverse, two classical issues are the following:

1. Internal Stresses Relaxation: Intermediate mechanical operations and/or heat treatment give birth to internal residual stresses. When these operations are followed by a machining, removing a significant quantity of material, the relaxations of these stresses may lead to unacceptable distortions. This problem is addressed either by adding an extra operation (shape correction) or by taking it into account in the machining program (hazardous and time-consuming to tune). In either case, this obviously leads to extra costs which may significantly increase the component price.
2. High strain level: The Superplastic Forming Process (SPF) takes advantage of the superplasticity of some materials to obtain components that may be complex (non-manifold geometries) from one single metal sheet. This can be achieved thanks to the property for these materials to accept very high strain levels (several hundred percents) when submitted to a certain temperature and range of strain rates. The latter point is achieved using a precisely controlled pressure cycle whose definition by a classical trial-and-error process may prove to be very challenging, if not impossible. Here again, the financial consequences are considerable.

The numerical simulation is a valuable tool in a context of cost reduction [1]. Indeed, it enables:

- To check the compatibility between the component to manufacture and the chosen process(es),
- To have access to what happens during the process for a better understanding which in turn may lead to improvements,
- To determine the different geometries (metal sheet, tooling),
- To tune the parameters of the process (pressure cycle, …).

These results lead to a shorter development phase and a more efficient manufacturing process.

However, a certain number of conditions have to be fulfilled to ensure the success of the simulation. They will be explained in a next paragraph. Then we will describe the different steps of a classical simulation. Next, three industrial examples will illustrate the application of such simulation within EADS group. Eventually, some prospects will be given.

2 Simulation of Manufacturing Process

2.1 Prerequisites for a successful simulation

The complete success of such simulations is related with the knowledge level of the process itself. This is of utmost importance in order to be sure than no important phenomena is missed. This task requires in-depth interviews of manufacturing people at various levels and a thorough observation of the process operations.

2.2 Steps of a Typical Simulation

The steps to perform the simulations are described hereafter:

1. Implementation of a physical material behavior model. This step may be optional since most finite element codes possess complex material laws. Nevertheless, many phenomena (for example stress relaxation) are not described easily or accurately enough by standard laws and require specific developments.
2. Identification of the material law parameters based on specific tests. Though these tests may be costly, one should resist to the temptation to suppress them, because of the consequences on the accuracy of the simulation.
3. Development of specific features in the finite element code. These developments are necessary to describe accurately some specific boundary conditions (for example a moving heating source for beam welding) or to transfer some results from one code to another.
4. Validation of the simulation on elementary and representative tests.
5. Application to the industrial problem and optimization of the process (Tooling and blank geometry, process parameters, …).

The completion of these steps allows the simulation to be successful and to bring cost savings. Experience shows that the suppression of certain steps (particularly the material characterization and the validation on simple tests) may lead to failure both technically and financially.

3 Industrial examples

Here follow three examples dealing with the aeronautic industry.

3.1 Rolling and machining of fuselage panels

A method to manufacture aircraft fuselage panels (figure 1.1) implies two steps

- cylindrical rolling of a plane metal sheet ,
- chemical milling for mass savings.

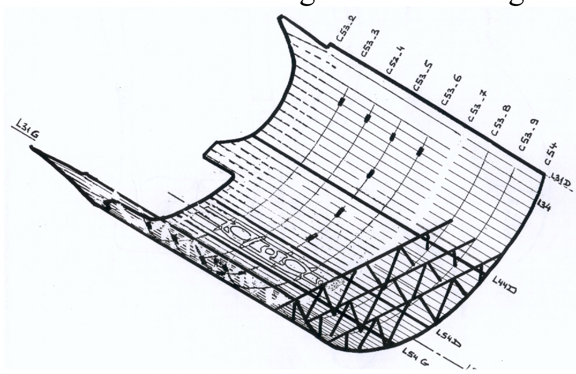

Figure 1.1 : Fuselage panel

The rolling operation (figure 1.2) generates a residual stress field within the thickness of the metal sheet. Since the thickness after chemical milling is not uniform (mass optimization), the stress relaxation leads to a change in the panel curvature whose magnitude is variable all along the part (figure 1.3). The panel is thus non longer cylindrical and requires extra-operations to obtain a correct geometry.

The simulation of this process achieved very good results compared to real panels. Then, it enables to propose a tooling modification in order to suppress the shape correction operation.

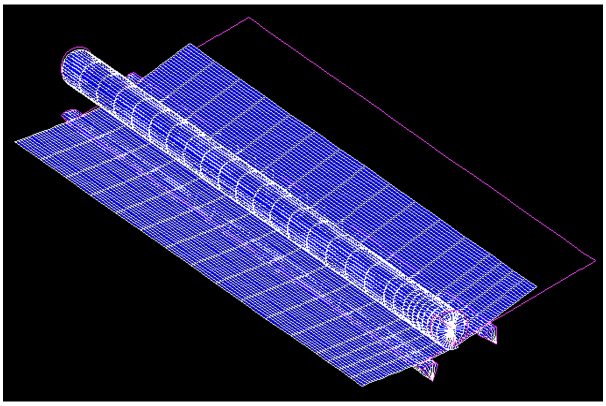

Figure 1.2 : Rolling of the panel

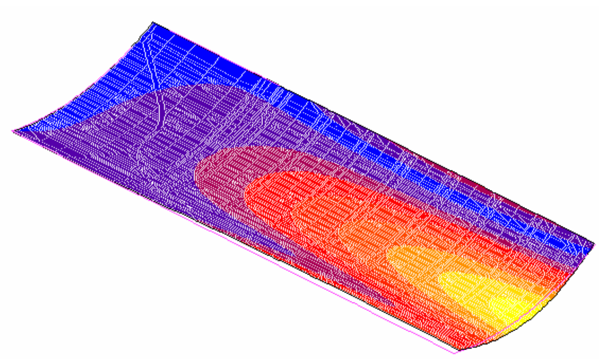

Figure 1.3 : Distortion after milling

3.2 Quenching and machining of forged parts

Bulky aluminum structural parts may be manufactured by a combination of quenching (to acquire improved mechanical properties by precipitation hardening) and milling. Here again, the first step yields residual stresses that generate distortions after milling (figures 2.1 and 2.2). A shape correction operation is thus required in order to match the dimensional tolerances.

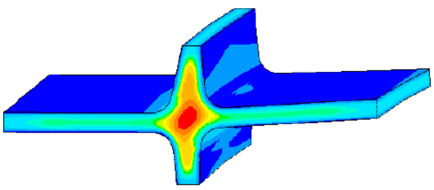

Figure 2.1: Residual stress field after forging

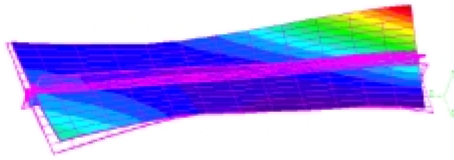

Figure 2.2: Distortions after milling

As for the previous example, the first objective was to reproduce the in-production process. A two-step analysis has been used:

1. An uncoupled thermomechanical simulation of the quenching phase has been performed. In this example (aluminum alloy), the stresses are generated by a non-uniform plastification level from the surface to the core. Temperature dependent mechanical properties are thus used to reproduce this phenomenon.
2. The milling step is modelized using a stress field mapping method [2][3]: the residual stresses are transferred from the initial geometry onto the final part mesh. A mechanical equilibrium analysis is then carried out to obtain the post-milling distortions.

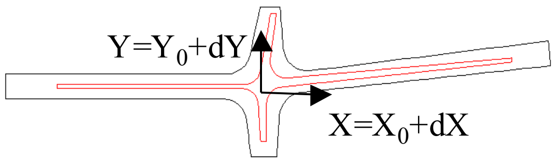

Figure 2.3: Research of optimal milling position

Experimental and numerical investigations have shown that the distortions depend on the position of the milled geometry within the initial one [4][5] (figure 2.3). An optimization software has been thus developed in order to minimize the final part distortions on simple parts [1]. This process is currently being applied to the actual industrial part with the objective to suppress (or at list significantly shorten) the shape correction phase.

3.3 Superplastic forming

The industrial development of the SPF process within EADS has been carried out with an intensive use of the numerical simulation since the 80's. A dedicated software is used on a daily-basis for the simulation of all the in-development parts. Spectacular results have been achieved in terms of shape complexity (figure 3.1).

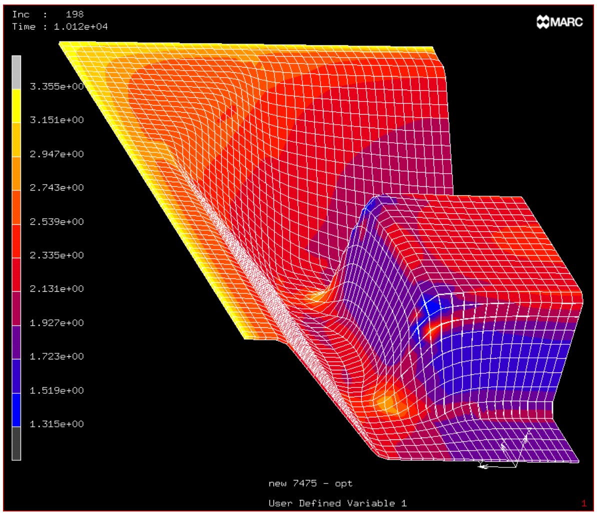

Figure 3.1: Simulation of a SPF part

The simulation is used to determine:

- The initial thickness of the metal sheet ,
- The pressure cycle used to maintain the super plasticity property during the whole process.

Using these simulations, the development phase is drastically reduced and requires the forming of only a few test parts to obtain the correct geometry.

4 Prospects

The demand for manufacturing process simulations has significantly increased within EADS group during the previous years.

In particular, a need has been expressed concerning dedicated software integrated within regular CAD/CAM environments, for a use by non finite-element-expert people.

Such dedicated tools are financially relevant when the simulation is used on a regular basis. When the need for the simulation is not recurrent or when the process to simulate requires many different steps, experts should perform the simulations for financial and technical efficiency.

5 Conclusion

This paper has emphasized the competitive advantage brought by the numerical simulation of manufacturing processes in terms of technical achievement, time and cost savings. Keys have been given for a successful implementation of such simulations within parts development cycles. Examples have illustrated the use of these tools within EADS group.

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