SIMULATION OF THE HOTFORMING PROCESS

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THEME

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SUMMARY

The hotforming process or press hardening as it is also called is increasingly popular. The advantage by reaching very high strength parts whilst keeping a low weight is very interesting not only for the automotive industry. The process however, is a quite complex one, and the need for accurate simulation is even higher than for normal stamping. The complexity of the process means that you will find the same complexity in the simulation, including the hot stamping, the cooling and the metallurgical effects. This paper looks into the different aspects giving an overview of what is possible today, and what is needed for the future.

1: The hot stamping process

Hot stamping (or hot forming) is an innovative process for manufacturing highly rigid parts while reducing both blank thickness and weight. It plays a major role in lightweight auto manufacturing, where the aim is to reduce vehicle weight while enhancing the rigidity of safety-relevant parts.

In contrast to the cold stamping of higher- and high-strength steels, the parts are hardened by the hot stamping and subsequent cooling process itself. In this way, steels with an original strength of 500 to 800N/mm2 can achieve strength of 1300 to 1700N/mm2 after heating, forming and cooling. When unhardened, these steels are less rigid and display much better forming characteristics.

Through the hot stamping process, however, the materials gain higher rigidity than higher- and high-strength steels. Good forming characteristics can therefore be combined with high rigidity levels.

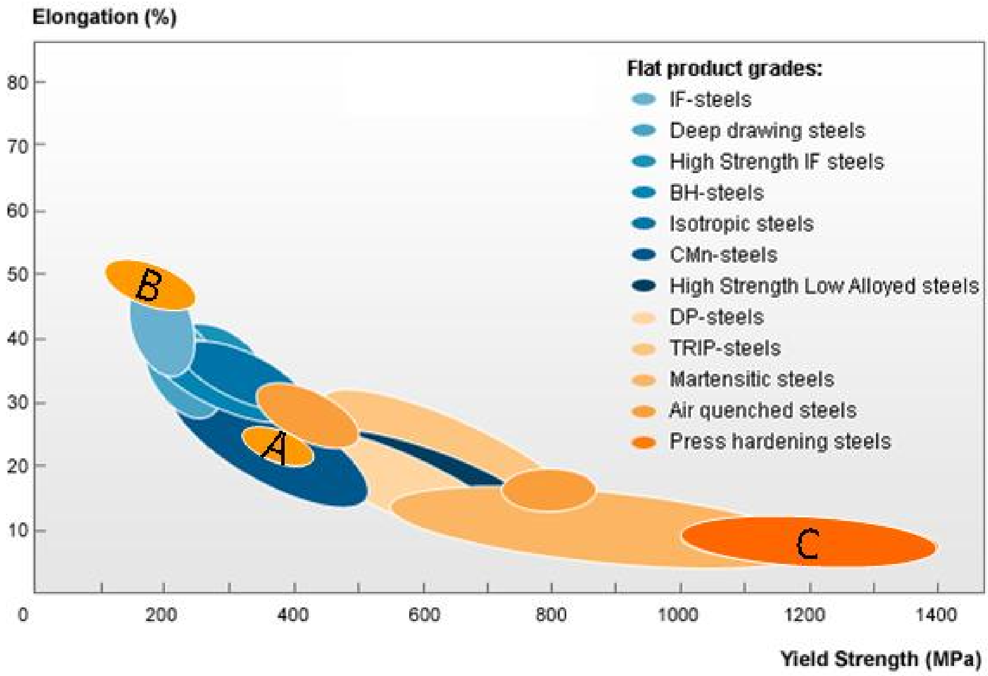

Figure 1: Typical hotforming material (Boron steel) A: as delivered; B: heated state – forming; C: after cooling: press hardened [1].

Through the hot stamping process, high-strength steels gain higher rigidity and good forming characteristics can be combined with high rigidity levels during the cooling process.

Hot stamping typically involves seven steps depicted in figure 1:

1. Straightening of sheet coil (uncoiling).

2. Mechanical cutting of pre-shaped sheets (blanking)

3. Oven heating of blanks to about 900°C

4. Rapid transfer of hot blanks to cooled press (< 10 s)

5. Rapid stamping of the part (tool closing ~ 0.5 s; forming ~ 1s)

6. Rapid quenching of formed part in the closed tools to about 200°C (10-20 s)

7. Removal from tools and further air cooling to ambient temperature.

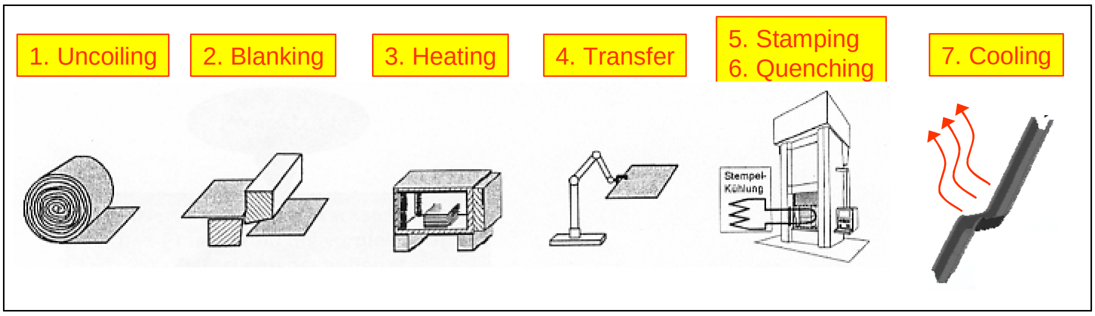

Figure 2: Schematic representation of hot stamping process.

Hot stamping offers three advantages over conventional heat drawing which make it attractive for the manufacture of crash relevant parts for automotive applications:

- High formability limits
- Low springback
- High part strength

2: Critical issues in hot stamping

However, in order to reach the final high strengths, the cooling phase is of crucial importance. High part strengths are achieved by appropriate control of the eutectoid reaction:

$$\gamma \text{ (Austenite)} \rightarrow \alpha \text{ (Ferrite)} + Fe_3C \text{ (Cementite)}$$

during quenching as indicated in figure 3.

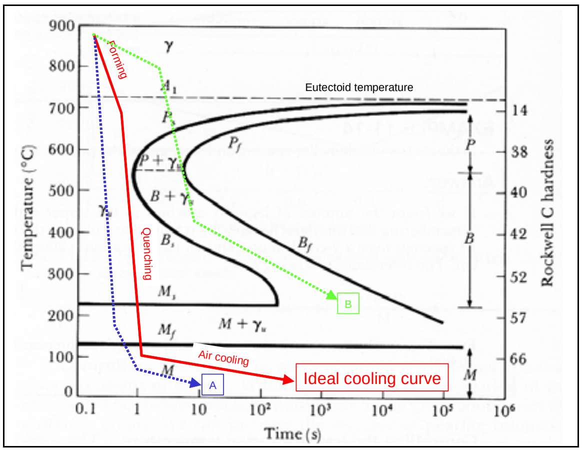

Figure 3: TTT Diagram for a Eutectoid Steel together with possible cooling curves during hot stamping

This means that besides the normal forming issues, the cooling phase needs to be taken into account. Both duration, and effectiveness and localisation of the cooling is important here.

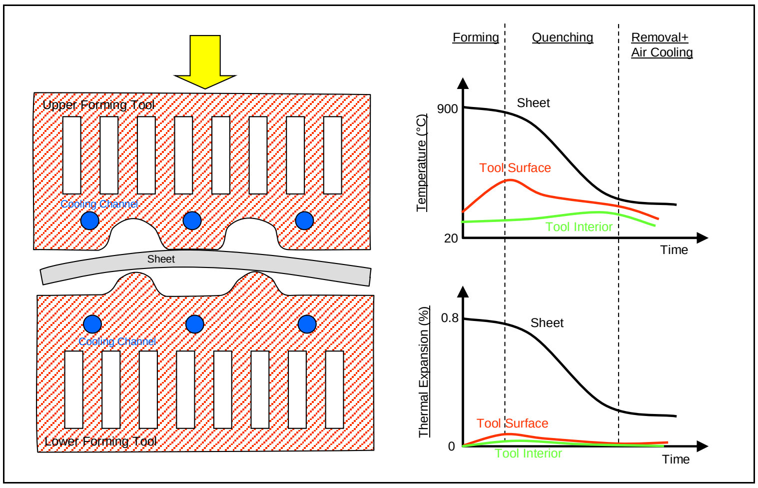

Figure 4: Typical temperature evolution and thermal expansion during the hotforming process

3: Simulating the process

An accurate simulation of the hot stamping process requires that all physical phenomena be properly captured as well as their interactions during the whole process. The following diagram depicts the physics underlying the hot stamping process.

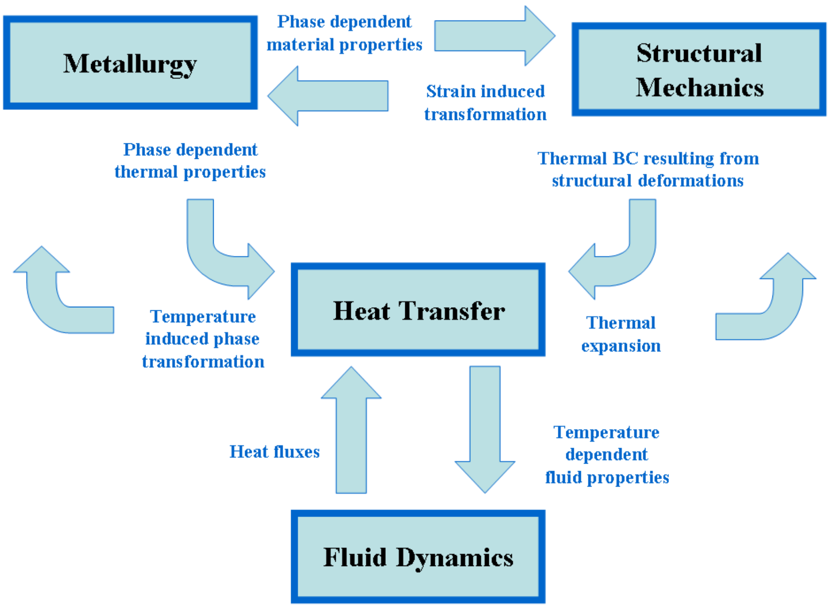

Figure 5: Different interactions during the hotforming process

Any simulation solution aimed at modelling hot stamping must be capable of capturing the above defined physical phenomena. In particular, for the heat transfer needed to capture the cooling the water flow in the cooling system must be apprehended in an accurate enough manner.

To be able to simulate the whole process accurately a program containing all these features would be needed:

- Multi-domain environment with sheet elements, volume elements and fluid dynamics
- Thermo-mechanical coupling between the sheet and volume elements and the fluid
- Appropriate material models for the above mentioned
- Phase transformation coupled to the above mentioned
- Heat transfer with the environment

Even if such a system would be available today, the required CPU times would be far too high for practical use with the given computational hardware available today. So in order to be able to simulate this process in an industrial usable way, there are basically two ways to go:

A) make simplified models or

B) decouple the process.

4: What is possible today?

What we want to show in this paper is an approach based on the decoupling of the process into:

- Forming simulation. With an assumed cooling – can we actually form the part without cracks/wrinkles?
- Cooling simulation: Can we with the given tool cooling reach the cooling rates we assumed in the forming simulation?
- Phase change simulation: Do we actually cool down fast enough?

Forming Simulation

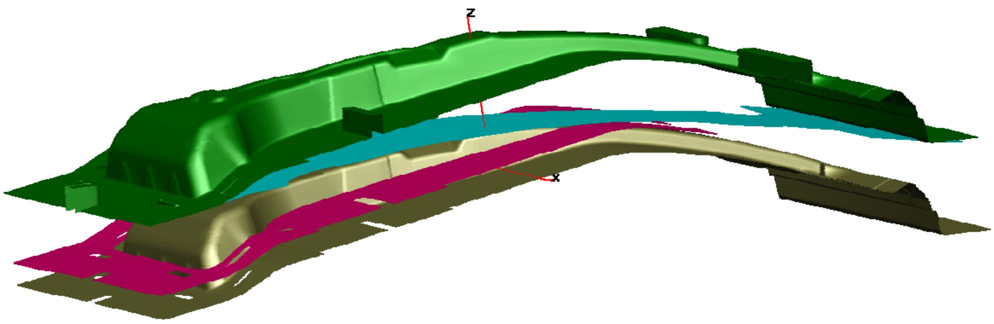

Figure 6: Sample B-Pillar with tools, courtesy of AP&T

As a sample for the forming simulation we have taken a B-Pillar from AP&T, see figure 6 for geometry and tools. The material is a trip steel, initial blank temperature assumed is 800°C and tool surface temperature is assumed 200°C. For this material we have four different hardening curves at four different temperatures shown in figure 7. Between these curves, the program will interpolate automatically.

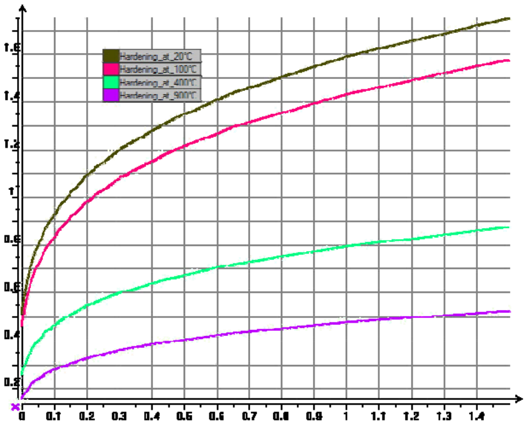

Figure 7: Temperature depending hardening curves

To show the effect of the good formability reached in heated state (see figure 1), we did a comparison to normal cold stamping. Using Pam-Stamp 2G to simulate the part, this given part clearly fails if tried to stamp at room temperature (see figure 8). Calculated with the hot stamping however the part is safe to manufacture. This shows that some of the additional cost for hot stamping can be regained by saving one step in the manufacturing process for a part like this.

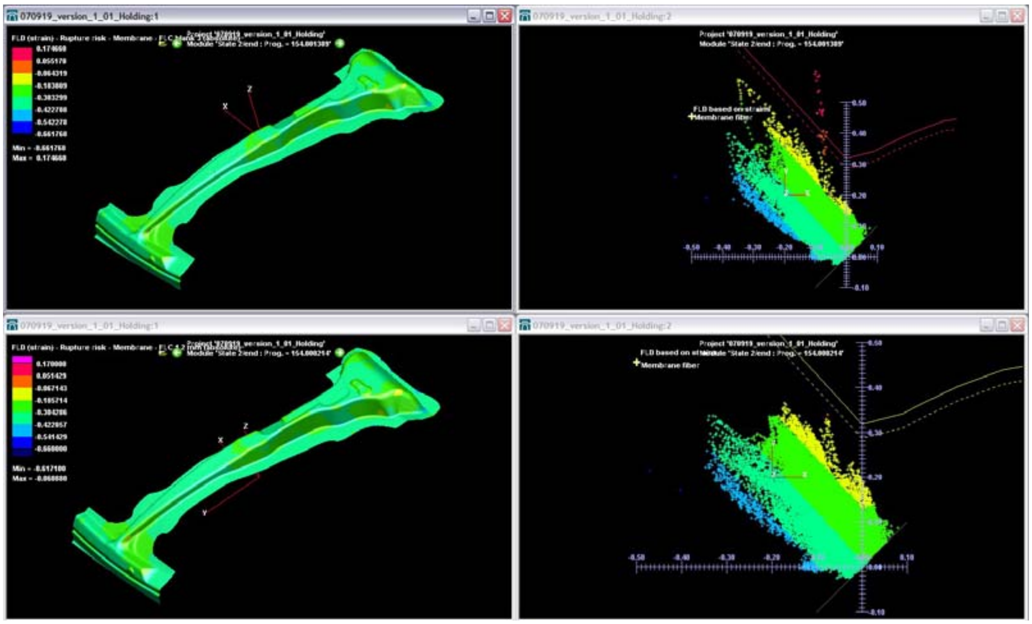

Figure 8: Comparison hot forming (bottom) to cold forming (top) – forming limit diagram

Also it is possible to use fast evaluation tools, such as Quickstamp in an early phase of process design to find a feasible die design and process setup before moving on to validation and tool manufacturing, see figure 9.

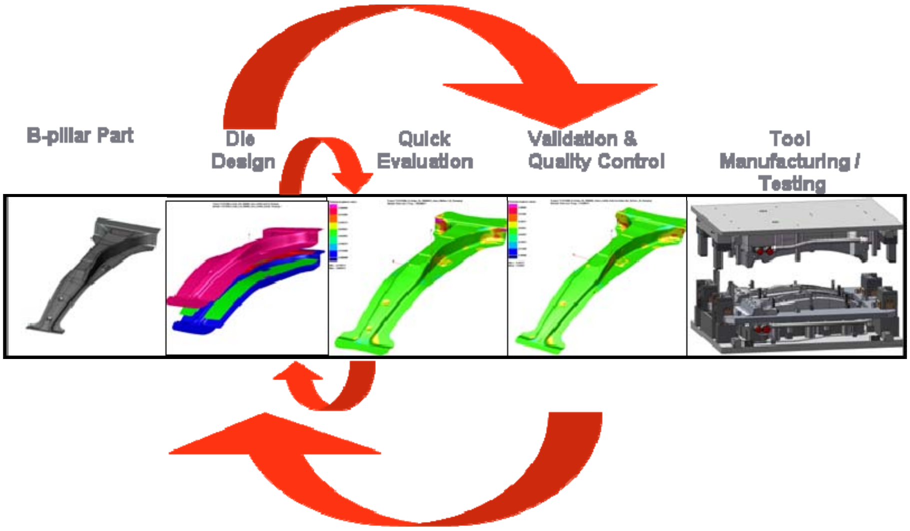

Figure 9: Working flow from part through die design, quick evaluation, validation to tool manufacturing [1].

Cooling Simulation

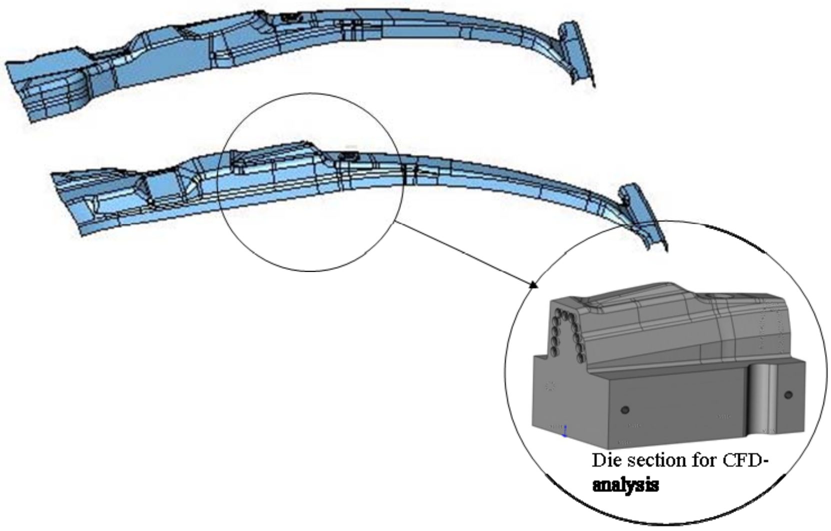

Figure 10: Section of the B-Pillar for CFD-analysis, courtesy of AP&T.

For the cooling simulation we used the same B-pillar as for the forming simulation, but used only one section of it to reduce CPU-times. The cooling liquid is water at a temperature of 27°C with a rate of 50l/min. The initial blank temperature is still assumed at 800°C. This section alone gave 1 118 746 Polyhedral cells. A multidomain grid consisting of solids (tool) and fluid (water) had to be used.

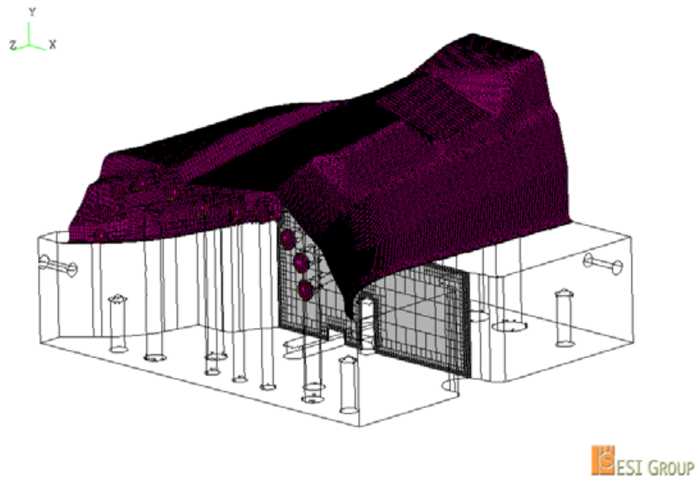

Figure 11: Grid for CFD computation

As a result of this CFD computation, the heat flux on the blank and the temperature distribution in the tools can be observed, see figure 12.

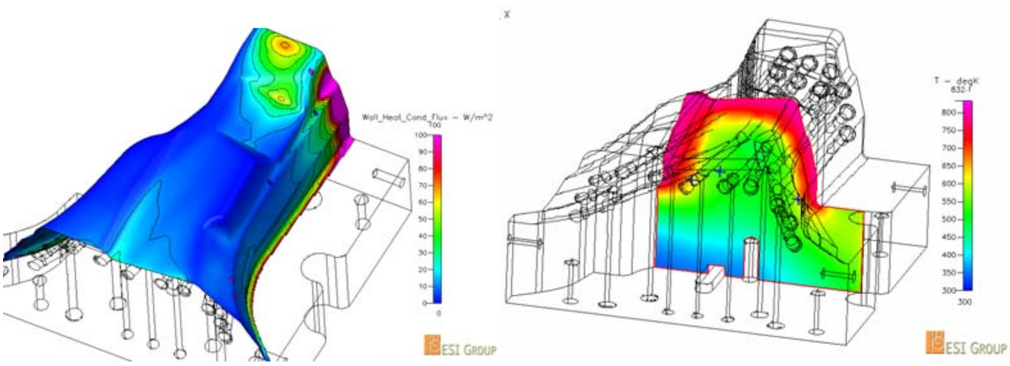

Figure 12: Heat flux on the blank (left) and temperature distribution in the tool (right)

Then taken the results from the CFD cooling simulation back to Pam-Stamp 2G, the quenching can be calculated, see figure 13.

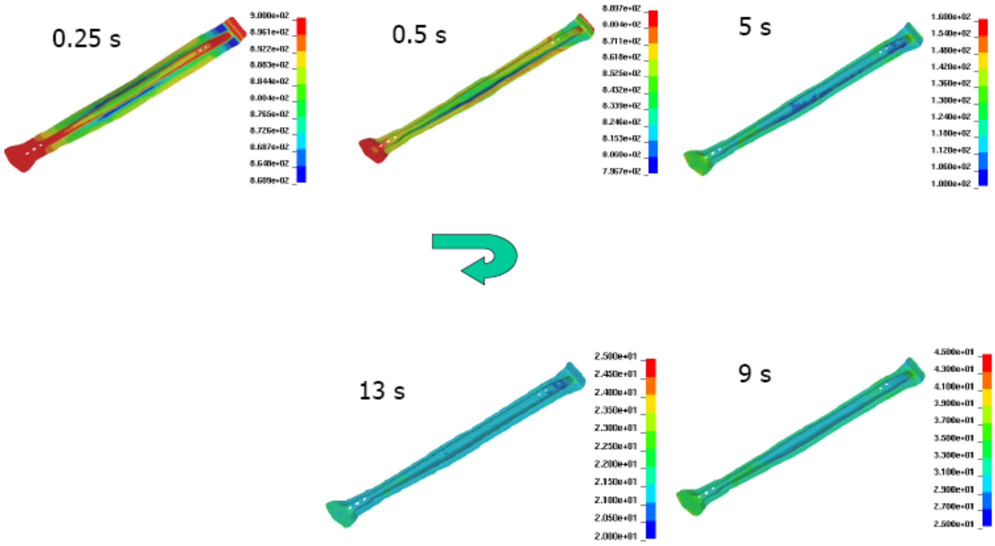

Figure 13: Quenching simulation [1] – temperature in the blank after the given number of seconds in the cooled tools.

Phase change Simulation

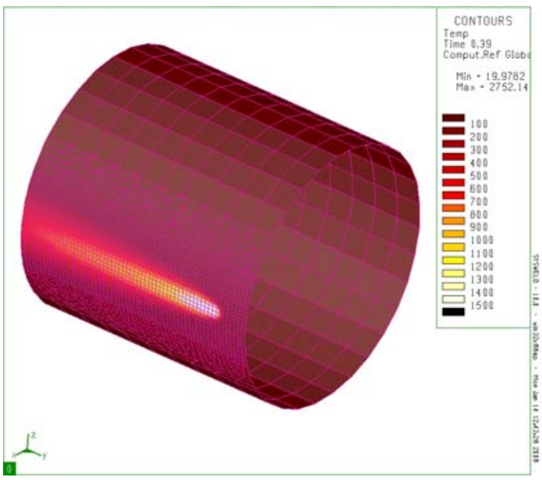

Figure 14: Sample for phase change simulation – temperature distribution

As a sample for the phase transformation simulation, an electron beam welding of a thin-walled tube was done. The material used was DP-600, and the temperature in the weld is slightly higher than found during hotforming, but interesting is the cool down, and the phase changes observed.

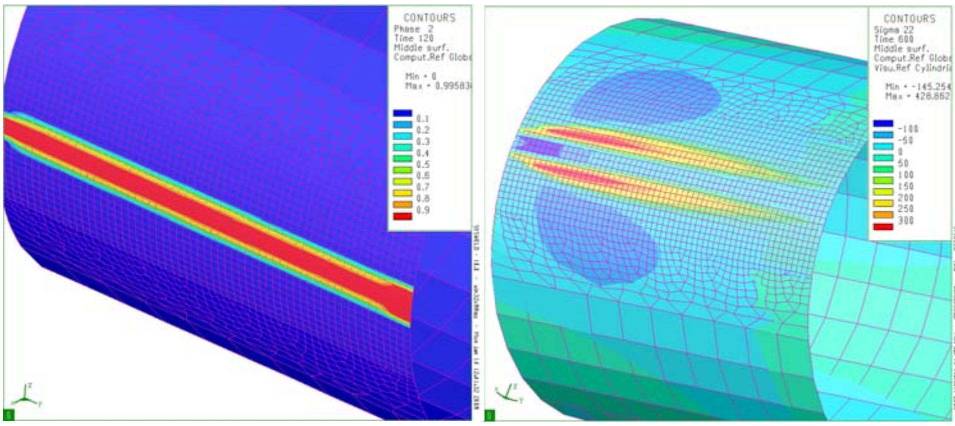

Figure 15: Results of phase change simulation; left: martensite after cooling; right: residual stresses

Using Syweld to simulate this, results can be found that there clearly is martensite after the tube has cooled down. Also residual stresses are visible which can lead to distortions of the blank after cool down.

5: Conclusion & future work

Decoupling the hotforming process gives today acceptable results for all parts of the process. However the errors done by assuming given temperature fields and not having a direct coupling between the forming, cooling and phase transformation software still exist and can't be neglected totally. By being careful when assuming temperatures the errors can be kept to a minimum.

Schuler [2] assumes that the number of hotformed parts will increase from 120 million parts in 2008 to 350 million parts produced worldwide in 2013. This means that the demand for accurate simulation solutions will increase in order to be able to understand the process and avoid costly mistakes in the part & process design.

For the simulation software industry this means finding solutions that provide an accurate enough simulation result whilst keeping the CPU times at acceptable rates and the use of the software user friendly. As this process – and the simulation of it – is still new, there is not yet enough experience as to which factors and parameters are important and which ones are not. Once this has been cleared out, it will allow the simplification of the models used. As this can happen, it should be possible to find a way to simulate the process in one go without decoupling it.

REFERENCES

[1] Johan Friberg, AP&T, AP&T Hot stamping seminar tour, Detroit, oct. 2008

[2] From presentation at the Hot sheet metal forming of high-performance steel conference in Kassel, Germany, October 2008