Micro-structure and temperature dependent failure modelling for analysis of hot sheet metal forming
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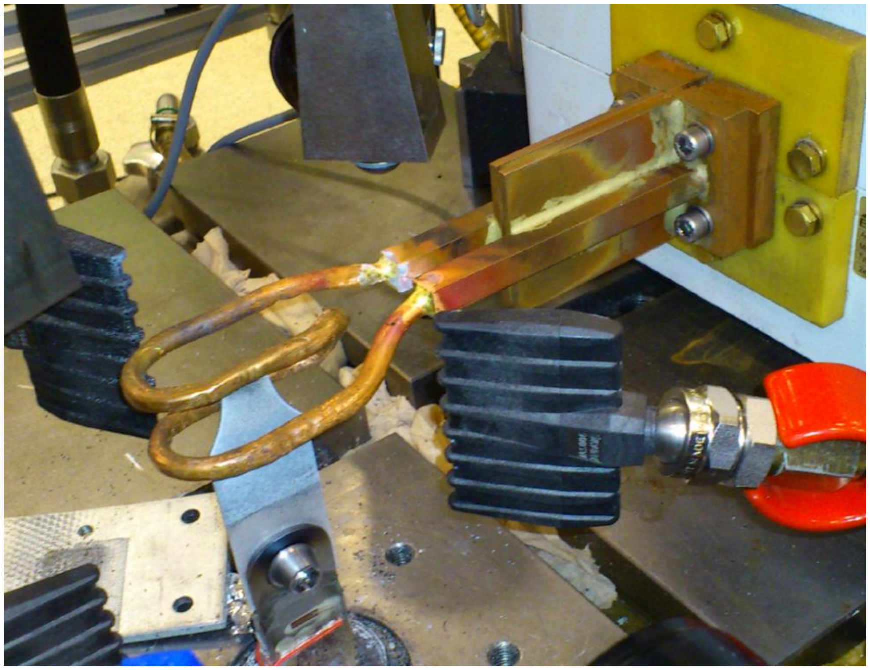

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Vehicle Development

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1. Executive summary

Objective and scope

Heat treatment is a very important industrial process for the production of ultra-high-strength components in boron steel. The mechanical properties of the material changes continuously during the process due to the temperature change during the hardening process. Simulation with good accuracy in the production process is important in order to optimize production parameters and thus achieve good efficiency and avoid material failure in production. The objective is to develop simulation models that can predict fracture at various combinations of temperature history and strain rate. The models will be implemented in the computer program for accurate simulation of the actual production process.

Experiments

To investigate the properties of materials at various stages during the curing process mimic the actual temperature history during the experiments. This means that the temperature is controlled during the heating, constant a fixed period to allow time austenite formed and forced cooling. Heating takes place by means of induction equipment whose output pull controlled by a feedback signal from a thermocouple welded to the specimen. In this way the temperature is ramped up to over 900 ° C, about 16 ° C / s While the hold time is handled automatically by the control system. The cooling during the curing process is done with compressed air and started after some time. Nozzles distribute air flow over the specimen surface, so that a sufficient and uniform rate of cooling (> 50 ° C / s) are achieved. The requirement for cooling rate determined on metallurgical grounds that it wants to achieve martensite without other phases have time to form. Since the goal is to identify the material properties during the curing process, the test must be done immediately when the temperature during cooling passes a preset temperature. Test machine and the measurement is triggered by a signal from the control system for the temperature. The principle shown in Figure 1.

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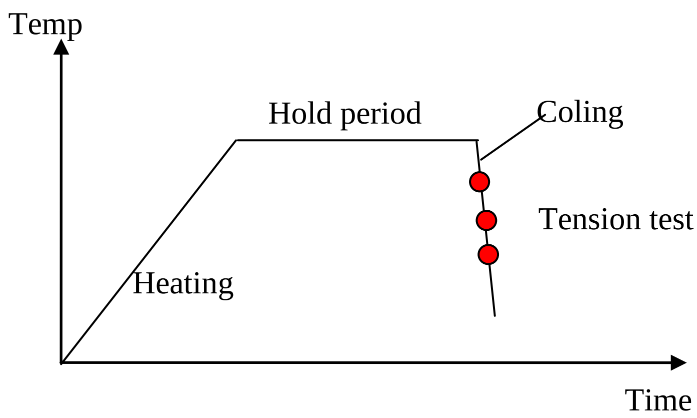

Figure 1. Principle of temperature history during testing

The experimental setup involves a servo-hydraulic testing machine, a cooled CCD (charged coupled device) camera mounted in front of the specimen with the lens axis perpendicular to a speckled surface and a computer for storing the images and evaluating the deformation fields. This test is done with a temperature profile of Figure 1 and at a high loading velocity. Therefore, the images taken with a very fast camera and the measurements have frame rates of up to approximately 50,000 frames per second used.

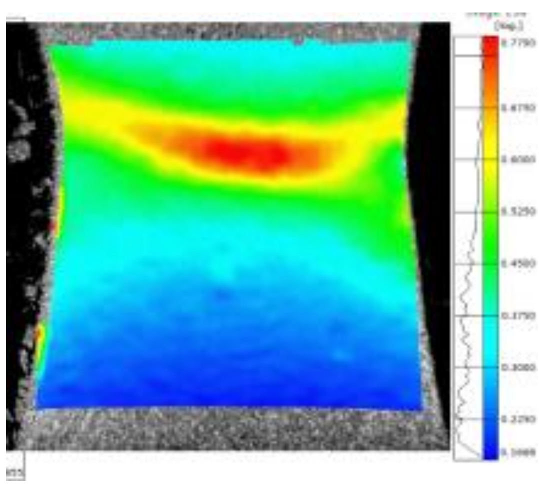

Figure 2. Strain field prior to failure.

During the observations of the specimen the focus has been on studying the plastic localization leading to fracture. Experiments results in a series of images of strain field developed during load to failure. From the last picture is the fracture strain determined. Here, experiments are carried out at several temperatures and several stories strain. Figure 6 shows examples of the results of image processing.

A physically based material model

The temperature and strain rates have a major effect on the movability of dislocations. The motions of dislocations can under certain stress situations start to move through the crystals resulting in macroscopic changes of the geometry. A material model based on dislocation physics and presented by Nemet-Nasser has been used in this work. Yield stress as function of effective plastic strain for different combinations of temperature and strain-rate are shown in Figure 3.

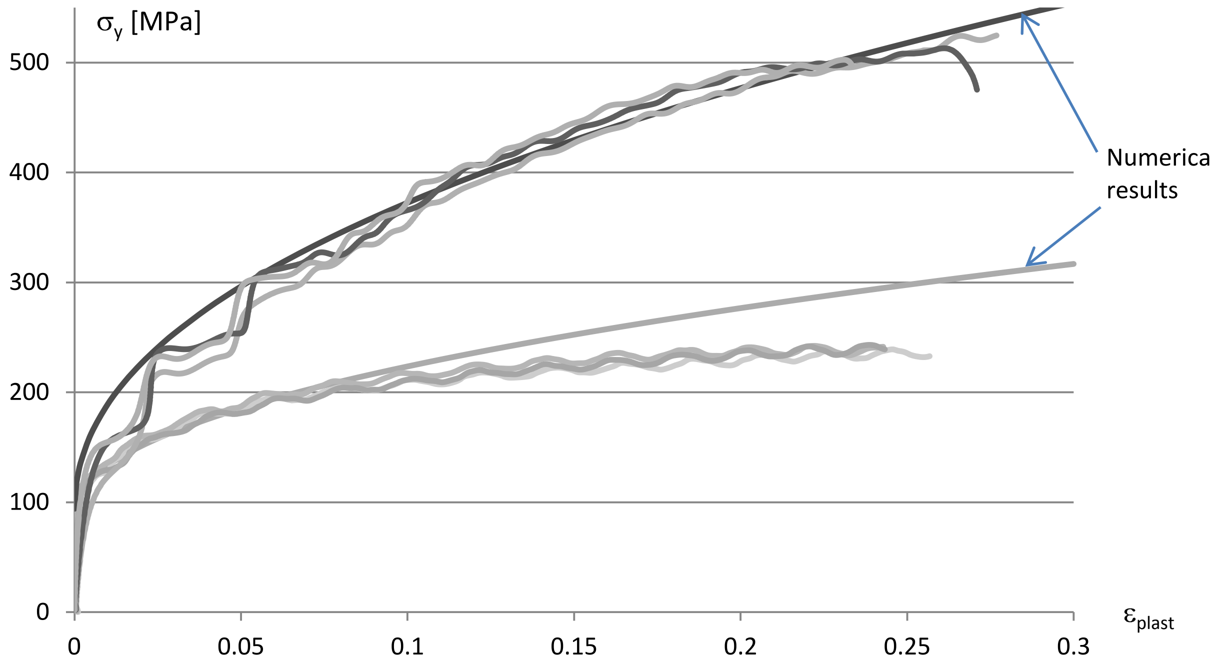

Figure 3. Experimental and numerical stress-strain relations for strain-rate1 s^{-1} at temperature 800 C (lower) and strain-rate 200 s^{-1} at temperature 600 C (upper).

Finite element simulations

Validation of the material model and associated material data has been carried out by comparing the results from experiments and FE simulation. We have chosen to compare the measured and calculated force-displacement and elongation up to failure. An hourglass-shaped test specimen geometry was used. This geometry provides an inhomogeneous state with respect to particular stress and strain in the area around the radius.

Measured and calculated force-displacement curves at 800 ° C and pull velocity 3.7 m / s are shown in Figure 4. Maximum force in the experiment is 8000 N and 7200 N. calculation The calculations used the curve of 0.1 s^{-1} as the static yield stress. Depending on how it is assumed that this curve looks at higher strains obtained different results. If, after the effective plastic strain of 0.25 allows the curve to continue with the same slope as the last curve segment results under the green curve 1.0. For the blue curve has a hardening corresponding to 0.01 times last segment been used. From DSP-measurement, the failure strain is estimated to 0.8 after about 7 mm displacement. The corresponding value from the calculation is 0.38 of Figure 5. Despite this discrepancy, the model can capture the localization occurs in the specimen. This is done by calculating about 7.4 mm and is shown in Figure 5. An strain of 0.8 is reached in the calculation by 8.5 mm displacement.

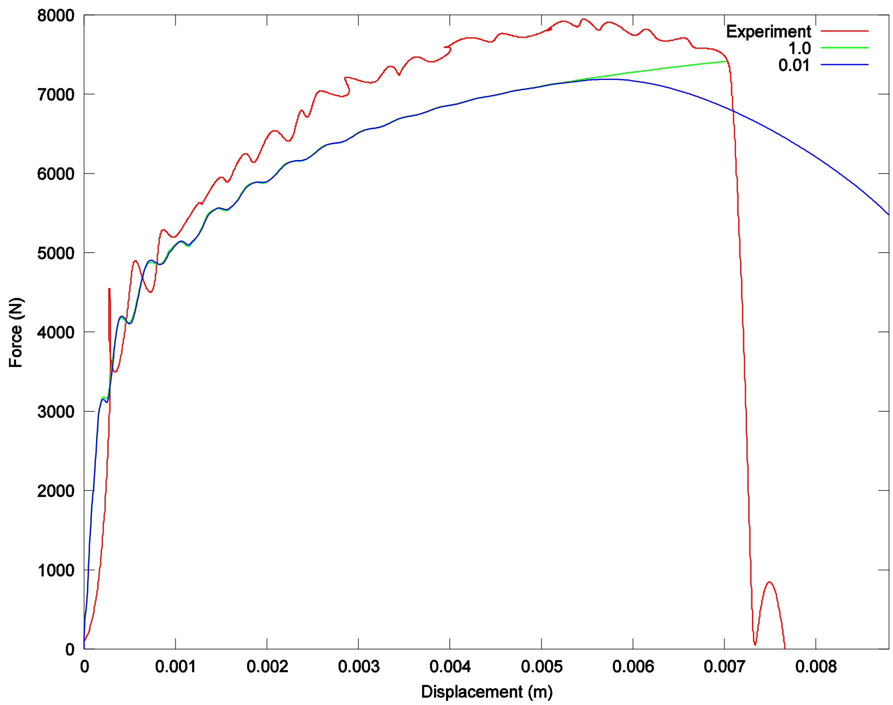

Figure 4. Measured and calculated force-displacement curves at 800 ºC and a velocity of 3.7 m/s.

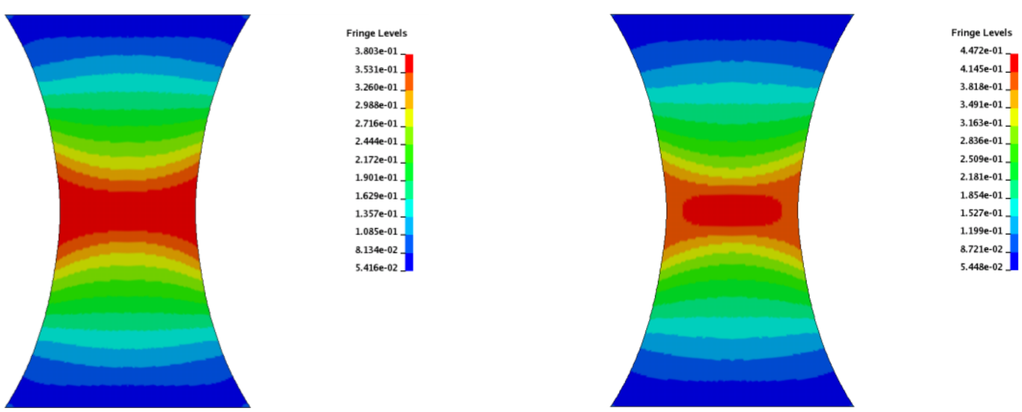

Figure 5. Calculated strain-field at 800 ºC and velocity 3.7 m/s at 7.0 mm (left) and 7.4 mm (right) displacement.

Conclusions

Experimental techniques are developed to enable determination of the input to the simulation models for predicting the load and fracture at various combinations of temperature history, microstructure and strain rate. Appropriate material models are evaluated and implemented in the finite element code. Validating simulations are performed and compared with experiments. The unique experimental methodology developed here together with simulation models provide great opportunities to further developing the press hardening process to manufacture new components in future car models.

2. Background

The press hardening process (or hot stamping) was invented back in the seventies in cooperation by former Norrbottens Järnverk and Luleå Tekniska Högskola. In summary, the process is based on the forming of hot blanks, in the austenitic state, to improve the formability as well as obtaining a final martensitic structure by subsequent rapid cooling in the forming tools. The technique can be summarized in the following steps, see also Figure 6.

1. Punching of blanks in uncoated boron steel, 22MnB5
2. Heating to austenitizing in a gas or electrical heated furnace
3. Handling of blanks between furnace and press
4. Forming and hardening in cooled tools
5. Internal transport to surface cleaning
6. Surface cleaning by shot blasting
7. Packing of components to customer

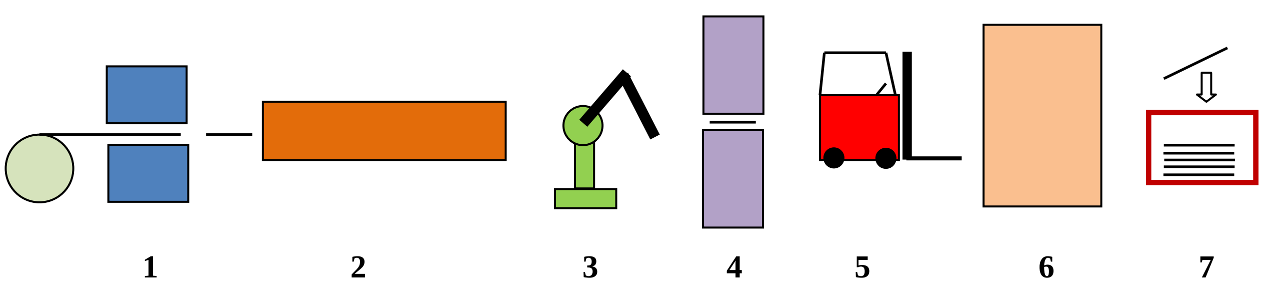

Figure 6. Illustration of a typical press hardening process.

In the press hardening process, a low alloyed steel material called 22MnB5 is commonly used due to its desirable properties and low price. The thickness range commonly used is in the interval 1 to 2 mm. Carbon content in the interval 0.2 to 0.25 wt% in combination with a low amount alloying elements provide good weldability. The steel in question has good hot forming characteristics and hardenability in combination with fine final mechanical properties. The fine hardenability is achieved by the addition of the alloying elements; manganese, chromium, silicon and boron. The majority of the components produced are for the automotive industry around the world. The usage of Ultra High Strength Steel (UHSS) components, to which the hardened boron steel belongs, is with advantage used as passive safety components due to its excellent mechanical properties. This in turn provides great weight reductions with maintained or increased passive safety. More specific examples of press hardened components are; a, b, c-pillars, side impact beams, roof bows and bumper beams, some of these are illustrated in Figure 7.

Reductions of the car body weight immediately reduce the energy usage which in turn gives a decrease in CO_2 emissions. The usage of UHSS components is expected to increase dramatically the coming years, not only in passenger cars but also in heavier vehicles such as trucks and buses. In the case of trucks, great savings both for the economy as well as environment are expected due to decreased curb weight and increased loading capacity.

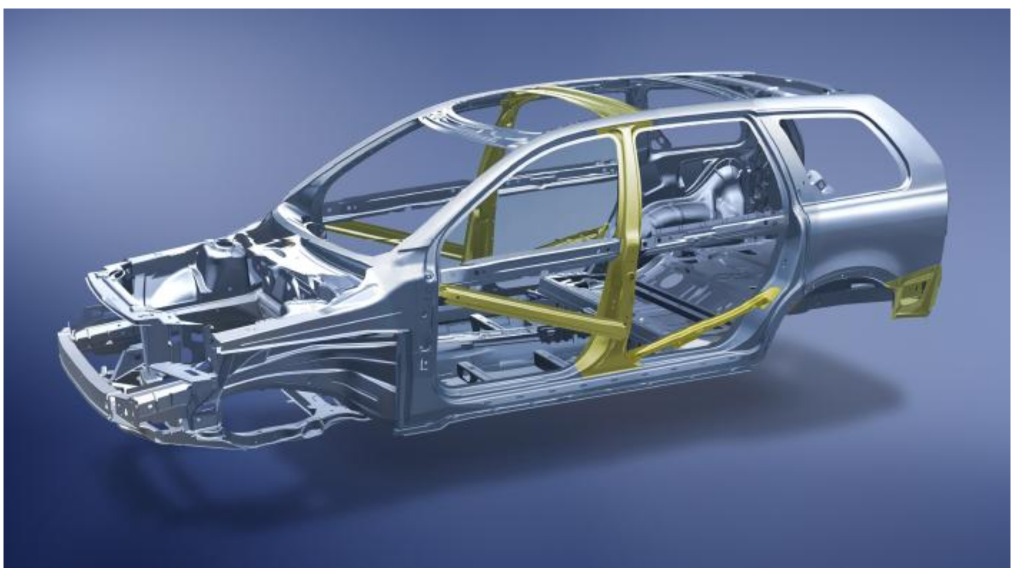

Figure 7. Illustration of some press hardened UHSS components, marked in yellow.

3. Objective

The project objective has been to further develop modelling and simulation of the forming and hardening in cooled tools (see step 4 in Figure 6). Further to develop experimental methods in order to achieve input data to the models.

4. Project realization

The project has been realized by the cooperative work between the partners Gestamp HardTech AB and Division Mechanics of Solid Materials at Luleå University of Technology.

5. Results and deliverables

5.1 Delivery to FFI-goals

One of the FFI-goal is to contribute significantly to reducing all losses in the production processing and significantly reduce the environmental impact of the manufacturing process. This project has strengthened the knowledge in the field of virtual manufacturing processing which created the possibilities to perform more accurate forming analysis. This result reduces the cost and above all the time for the development of new hot forming components for the automotive industry.

6. Dissemination and publications

6.1 Knowledge and results dissemination

The implemented and calibrated model for hot forming analysis is now used daily by forming analyst at Gestamp's R&D- and Tech centers in Europe.

6.2 Publications

No external publications have been released at the writing moment, but participation with project posters at FFI-conferences.

7. Conclusions and future research

To obtain input data for simulation models a methodology for strain-field measurements in the hot state and at high strain rates have been developed. Tensile test specimen with geometries that provide different stress conditions can be tested under conditions comparable with the state of the formed blank in the hot forming process. Performed tensile tests in the hot state are used for calibration of the developed material model which is used for hot forming analysis.

The developed and implemented model takes into account the material's temperature and strain-rate dependent hardening / softening in the austenitic state. The model does not include temperature dependent relationships for local elongation for use in a general temperature history, which was one of the objectives of the project.

8. Participating parties and contact person

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