DEVELOPMENT OF A HYBRID DEEP DRAWING PROCESS TO REDUCE SPRINGBACK OF AHSS

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Abstract. In future, the steel manufacturers will strive for the implementation of Advanced High Strength Steels (AHSS) in the automotive industry to reduce mass and improve structural performance. A key challenge is the definition of optimal and cost effective processes as well as solutions to introduce complex steel products in cold forming. However, the application of these AHSS often leads to formability problems such as springback. One promising approach in order to minimize springback is the relaxation of stress through the targeted heating of materials in the radius area after the deep drawing process. In this study, experiments are conducted on a Dual Phase (DP) and TWining Induced Plasticity (TWIP) steel for the process feasibility study. This work analyses the influence of various heat treatment temperatures on the springback reduction of deep drawn AHSS.

Keywords: Springback, Advanced High Strength Steel, Forming, Hybrid deep drawing, Heat treatment, Induction heating

1. Introduction

The increasing demand for lightweight structures requires the use of new generation of steels. The Advanced High Strength Steels (Dual Phase, TWinning Induced Plasticity, TRansformation Induced Plasticity, Complex Phase, Martensitic Steel) can be classified into the groups of high strength (steels with tensile strengths of 270-700 MPa) and ultra-high strength steels (tensile strengths over 700 MPa), depending on their mechanical properties. Thus the AHSS overlap the tensile strength range of HSS and UHSS [1]. For car-body parts, AHSS steels offer greater potential for savings. Due to the higher strength of AHSS, car-body and chassis parts can be produced with lower sheet thickness, which leads to significant weight saving and consequently to cost saving. Therefore energy saving and CO₂ carbon dioxide reductions can be achieved. [2][3]

However, the application of these steels in the automotive industry is difficult and limited due to severe springback after forming. In order to have this problem under control, an additional measure is necessary during the tool design, so that component tolerances are complied. This leads to longer developing times and consequently to higher costs. A positive effect in springback is possible with draw beads, the right level force and regulation of the clamping force. Also a smaller tool radius, lower tool clearance and higher clamping forces are potential solution approaches for the reduction of springback [4]. Two possible solutions to compensate the springback can be the use of modified tools, also called “false” tools, or overbending. Prediction of springback is essential for developing a tool design and defining right process parameters in sheet metal stamping operation. [5][6]

The local heat treatment concept is a new hybrid deep drawing process in order to reduce springback. The new hybrid process for springback reduction is illustrated in Figure 1. It is a combination of deep drawing and local induction heating in one step. Direct heating in closed dies after deep drawing in the area of residual stress leads to a relieve of stress and decrease of springback as well. On the other side, by rapid cooling through the cooling channels integrated in the punch, increase of material strength can be realized. The reason for this hardening phenomena is caused due to the changes in the material microstructure.
This work shows the potential of the hybrid deep drawing process for springback reduction. To define the process window for the hybrid deep drawing process, the main focus is on the material behavior after induction heat treatment with peak temperatures between 400°C and 900°C. Therefore, different metallographic specimens are analyzed and the final mechanical properties are evaluated.

2. Materials

Two UHSS steels was investigated in this work, a non-commercial new Dual Phase steel (designated as Mat A in the following text) and an austenitic high manganese TWinning Induced Plasticity steel (designated as Mat B in the following text). Both materials are cold rolled steels and have a sheet thickness of 1.5 mm. To evaluate the mechanical properties of Mat A and Mat B tensile tests were performed according to the DIN EN ISO 6892-1 [7] at room temperature in rolling direction. The mechanical properties of the two investigated UHSS grades are listed in Table 1.

| Steel | Thickness t in mm | Yield Strength YS in MPa | Ultimate Tensile Strength UTS in MPa | Uniform Elongation U.E. in % | Total Elongation T.E. in % |
|-------|-------------------|---------------------------|--------------------------------------|-----------------------------|--------------------------|
| Mat A | 1.5               | 1077                      | 1269                                 | > 6                         | > 12                     |
| Mat B | 1.5               | 545                       | 1067                                 | > 60                        | > 60                     |

Both steels exhibit a completely different macroscopic material behavior because of their different microstructural characteristic. The investigated Mat A steel had a ferritic matrix containing martensite, bainite, tempered martensite and small amounts of retained austenite, whereas Mat B steel is characterized by austenitic microstructure. In Figure 2, the microstructure of both materials in delivery condition without heat treatment is illustrated. The chemical compositions of the studied UHS steels are given in Table 2.
Table 2. Chemical composition (wt %) of the studied UHS steels used in the experiments.

|      | C  | Mn  | Si  | P   | S   | Cr  | Mo  | Al  | Ni  | Cu  | Nb  | Fe  |
|------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Mat A| 0.21 | 2.88 | 0.8 | 0.006 | 0.007 | <0.5 | 0.01 | <0.02 | Bal |
| Mat B| 0.67 | 16.56 | 0.13 | 0.011 | <0.005 | <0.2 | 0.03 | <0.005 | Bal |

3. Experimental Procedure

3.1. Dilatometric study

Dilatometric test have been performed with a dilatometer DIL805A from Bähr at the Institute of Materials Science, Joining and Forming at TU Graz in order to apply a heating and cooling cycles on the materials. Samples were machined in the rolling direction from sheet, with 5 mm wide and 12 mm long dimensions. The sample length is directly measured with a resolution of ±0.05µm. The non-deformed specimens were exposed under vacuum at approximately 10⁻⁴ mbar to the heat setting i.e. heated up to the temperatures of 400°C; 500°C; 600°C; 700°C; 800°C and 900°C and cooled down to room temperature. The sample temperature is measured by a thermocouple welded to its surface using a precision welder and jig supplied by the dilatometer manufacturer. Both length increase $\Delta L$ and temperature $T$ changes were measured during heating and cooling for each temperature setting.

3.2. Preparation and Measurement

Transverse sections were taken from the dilatometric samples. Samples were mounted in phenolic and fine-ground, rough polished, and final polished using standard manual techniques. For Mat A Nital 3% was used as chemical etched medium and the austenite grain in Mat B was determined at samples etched with Bechet-Beaujard. The sample microstructures of the UHS steels were studied using light optical microscopy operating in bright field illumination. Hardness testing was performed on polished samples by means of an Emco Test using a Vickers indenter, which was set for 25 s dwell. Calibration blocks were used to verify that the tester was operating properly with the indenter.

4. Results

4.1. Dilatometric curves

The used heating rate during the dilatometric experiments was 220 °C/s. As shown in Figure 3-a, for the highest annealing temperature of 900°C the start- and finishing temperature for austenite formation was determined at $A_1 = 755°C \pm 2°C$ and $A_3 = 843°C \pm 3°C$, respectively. For a cooling rate of 145 °C/s the start temperature for martensite formation $M_S$ started at about 365°C. Figure 3-b shows the dilatometric curve of Mat B without a phase transformation at increased temperatures, normally expected in case of an austenitic steel. The sample expands to 200 µm.

![Figure 3. Dilatometric curves of heating and cooling a) Mat A and b) Mat B with the peak temperature of 900°C.](image-url)
4.2. Microstructures and Hardening

Fehler! Verweisquelle konnte nicht gefunden werden. showed the room temperature microstructures of Mat A at different peak temperatures. This material has a complex phase composition at each peak temperatures. Ferrite, martensite, tempered martensite, bainite and residual austenite are present at lower peak temperatures in different amounts in the microstructure. Between 700°C and 900°C occurs austenitization of the steel, and thus leads to more changes in microstructure and strength. At the peak temperature of 900°C a fully austenitization take place and at high cooling rates a martensitic microstructure is formed; as presented in Fehler! Verweisquelle konnte nicht gefunden werden.-f.

![Microstructures of heat treated Mat A samples at various peak temperatures](image)

**Figure 4.** Microstructures of the heat treated Mat A samples at various peak temperatures at a) 400°C, b) 500°C, c) 600°C, d) 700°C, e) 800°C and f) 900°C.

After the heat treatment at different peak temperatures, Mat B always has an austenitic microstructure as shown in Figure 5. In the undeformed conditions no changes in the microstructure of Mat B was observed with the light optical microscope. Due to the non-deformed dilatometric testing, there is no appearance of twinning of the austenite grains in Mat B.

Figure 6 showed the measured hardness of the UHS steels at room temperature after induction post heating with different peak temperatures. In case of Mat A, the initial hardness is similar to the delivery state of 385HV10 until the peak temperature of 400°C. At higher increasing peak temperatures the hardness is constantly dropping from 385 HV10 at 400°C to about 295 HV10 at heat treatment temperature of 700°C. Due to the annealing of the microstructure the hardness decrease in this range of temperature. The hardness of Mat A achieves values of maximum 518HV10 after the induction heat treatment with the peak temperature of 800°C. This hardness increase is a result of the microstructure transformation in the material.

The hardness of the Mat B in as rolled condition was 255HV10, whereas after heating and cooling, there was a slight difference of about 5% in comparison with the reference material, as presented in Figure 6.
Figure 5. Microstructures of the heat treated Mat B samples at various peak temperatures at a) 400°C b) 500°C c) 600°C d) 700°C e) 800°C f) 900°C.

Figure 6. Hardness profile of Mat A and Mat B across the sheet thickness at various peak temperatures.

4.3. Bending experiments

At the Institute of Material Science, Joining and Forming a test system with the 10kHz and the 100kHz inverter with a respective rated power of 120kW and 160kW is available. The face inductor was used for bending experiments with a local induction heating procedure. The preliminary trials was carried out in a scaled process to show a potential for the springback reduction during a hybrid deep drawing process. The samples were bended in a simple tool with and without heating in the radii area. Figure 7-a) shows the trial setup with the induction heater. In case of post heat treatment, the samples was cooled on air to the room temperature. After both processes the bending angels were measured and the differences were analysed. In order to analyze this process an exact temperature measurement is
essential during the whole heat treatment. For this purpose, hole with a diameter of 0.55 mm and a depth of approx. 30 mm was inserted into the sheet. Sheathed thermocouple, with a diameter of 0.5 mm and a maximum sampling rate of 7 Hz, was used to measure the heat inside the blank. These heat traces were recorded during the heating and cooling phases. The induction power used for heating was 40% and the heating rate 50°C/s to sheet temperature of 900°C. Due to the slower cooling rate on air compared with quenching in dilatometer, material have not reached fully phase transformation in martensit as in delatometric testing.

As showed in Figure 7-b), the big potential for springback reduction is with Mat A possible, where a 16 degrees reduction was achieved. The hardness of Mat A achieves values of 345HV10 after the induction heat treatment and air cooling. In hybrid deep drawing process due to contact between part and the forming tool will be increased the cooling rate and therefore higher strength will be achieved. In the case of the Mat B no significant progress in reducing springback was observed during this trials, as presented in Figure 7-c).

![Figure 7. Bending with and without local heat treatment a) Induction heaters, b) Mat A and c) Mat B.](image)

5. Conclusion

In this paper a feasibility studies for springback compensation of ultrahigh strength steel with a local induction heat treatment in the bending area are presented. Summarizing, the following conclusions were obtained:

- New process approaches are regarded essential in order to optimize the forming process of AHSS in term of minimizing springback.
- The local heat treatment in forming dies with the objective of relieving residual stress, changing the microstructure and reducing therefore springback can be successfully performed through induction heating.
- A feasibility study was made to show the potential of this idea on two UHS steel.
- The heat treatment process i.e. the heating rate, annealing temperature and the cooling rate has a significant impact on the hardness values in case of DP steel, due to reaching different martensite contents.
- DP steel in comparison with TWIP steel, showed a better potential for the hybrid deep drawing process in order to reduce springback.

6. Outlook

Very important point is the modelling of a FEM simulation to describe the hybrid deep drawing process by using a commercial FEM software. This simulation model needs to be validated due to experimental data obtained from heat treatment and forming process. Development and the manufacturing of an heat treatment tool should be made with the ability to work under near-production conditions. Another focal point is Liquid Metal Embrittlement. This is a phenomenon of practical importance, where certain ductile metals experience drastic loss in tensile ductility or undergo brittle fracture when exposed to specific liquid metals. Through standard thermal-mechanical testing with GLEEBLE system will be used to study the sensitivity of the Dual Phase steel to the LME phenomena and the influence of different process parameters such as heating rate, peak temperature, holding time, cooling and strain rate will be analyzed. Also EDX analyses must be done to reveal the presence of zinc on the “fracture” surfaces.
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