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Local heat treatment in draw bending for profiles of manganese boron steel 22MnB5

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Abstract

Due to the increasing demand for vehicles with a low fuel consumption and consequently low emissions, lightweight construction is an important task in the automotive industry. High-strength profile parts reduce the total weight of the vehicle while maintaining a high bending-resistance. Draw bending combined with inductive sheet heating and subsequent cooling represents a cost-effective and economic concept for producing partially hardened profiles for small batch sizes. This paper deals with experimental investigations to optimize and examine heating and cooling in the process chain of draw bending. After designing the process by numerical simulation, the existing draw bending machine of the IFUM was expanded by an inductive heating unit and a cooling system. Subsequently, new experiments on the implementation of a heat treatment during draw bending were carried out with this machine. In the course of these experiments, the determined process limits were recorded based on the required drawing force, the temperature courses in the process and the respective hardness values. These values served to evaluate and validate the results of the numerical simulation. By means of heating the material before it enters the forming die, it could be shown that it is possible to form super high-strength-profile components through draw bending. The material was heated up to austenitization temperature by a surface inductor and cooled by the draw bending tool and the additional air cooling. The material used was the uncoated manganese-boron steel 22MnB5. Good results with regard to process and part quality were obtained by means of an upstream heating. The comparison with the simulation also showed a high degree of similarity and consequently confirmed the results of the numerical representation of the process. Thus the general feasibility of integrating a heat-treatment into a draw bending operation was successfully proved.

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Keywords: draw bending, integrated heat-treatment, 22MnB5

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1. Introduction

More flexible production methods for individual profiles gain importance against the background of constantly extending product ranges and enhanced requirements in the industrial environment. Draw bending is one of these flexible methods for the production of profiles, defined by DIN 8586 as bend forming with linear tool motion. It is an inexpensive alternative for manufacturing profile parts in small quantities. Possible profiles are standard profiles such as U-, C-, L-, Z-, or hat profiles. In draw bending, a drawing cushion (gripper wagon) grabs the bottom of the sheet and draws it through the drawing gap of the matrix. Thus, a flat board or steel belt from a coil is formed to a profile by a fixed and rigid matrix. The process principle of draw bending is presented in figure 1. It is also possible to use several forming steps to increase the complexity of the profiles. While designing the draw bending tools, the springback of the profiles has to be taken into consideration. In draw bending, tool abrasion is higher than with rolling tools, so that tool life is decreased [1, 2, 3, 4].

A tool adjustment during the draw bending process enables the production of stress-adapted profiles. Stress-adapted profiles are used in steel construction, building industry, aircraft construction, rail vehicles and in single cases in the automotive industry. For the automotive industry, the production of draw-bended collision elements for the doors or the sides in small batch sizes would be possible. Due to low machine and tool costs, the potential of draw bending can be seen more particularly in prototype, small and medium batch production. This procedure allows the cost-effective production of weight-optimized parts. Since draw bending enables us to create component geometries that could formerly only be achieved by deep drawing, it is possible to replace the production of simple deep-drawn parts [1, 5, 6].

In view of the industrial demand for minimizing material use and component weight, hot stamping has gained more and more importance in recent years. The advantages of this production method are a reduced material employment and consequently also reduced weight, whilst still offering the same or even higher strength achieved through conventional forming operations for shaped sheet components. In hot stamping, the plate is heated to approx. 1000 °C during the heating phase, in order to achieve an austenitic structure. The manganese-boron steel 22MnB5 is commonly used for hot stamping. A targeted fast cooling of the component after forming with cooling rates over 27 K/s causes the austenite to transform into martensite and thus sets the desired material properties [7, 8, 9]. The resulting advantages over cold forming are lower forming forces, higher deformability, high dimensional and contouring accuracy, low elastic rebound as well as reduced residual stresses. Despite the considerably higher costs in comparison to conventional production, the proportion of vehicle components produced with this method is steadily rising, as well as the number of production plants for this purpose. So far, the crash- and safety-relevant body components such as cross members, side impact bars, A- and B-pillars as well as roof frames and parts of the floor unit are mainly being produced through hot stamping [10, 11, 12]. The combination of draw bending and hot stamping allows a targeted setting of local material properties by means of integrating a heat treatment in the draw bending operation. Thus, the advantages of draw bending can be combined with those of heat treatment, expanding the basis for a cost-effective production of load-adjusted ultra high-strength-profile components for lightweight construction [13]. The combination of roll forming and heat treatment was investigated in [14].

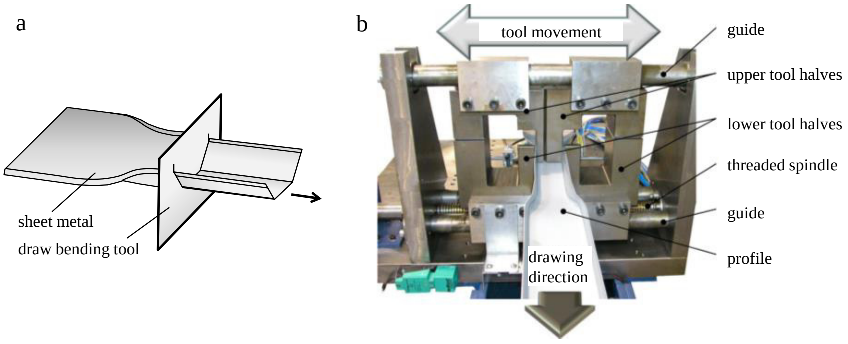

Fig. 1: Process principle of single-stage draw bending (a) schematic layout, (b) installation with tool adjustment during the draw bending process at the IFUM according to [4, 1]

2. Experimental and numerical Implementation of the Integrated Heat Treatment for Draw Bending

The experimental setup of the utilized draw bending application with integrated heat treatment is shown in figure 2. Due to different inductor geometries, heating of the whole profile as well as partial heating of the bottom area is possible. Heating is effected at occurs with temperatures higher than 980°C. The sheet metal (1 mm; 1.25 mm) is initially heated by induction, then formed by a fixed, water-cooled matrix and finally cooled by compressed air to a temperature below 150°C. Force and temperature measurement are carried out during the whole process chain of draw bending. The U-profile used for the tests was designed by means of numerical simulation.

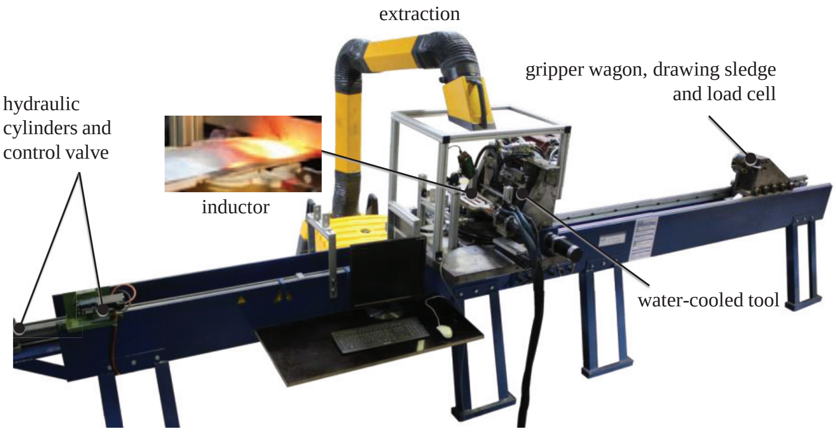

Fig. 2: Draw bending application with integrated heat treatment at the Institute of Forming Technology and Machines (IFUM)

Within the preliminary design, tests were carried out to investigate the optimum heating parameters of the process. To define the heating rate, the maximum heating temperature, the holding time after heating and the cooling rate for the draw bending process, samples were heat-treated at the forming and quenching dilatometer at the IFUM and the resulting hardness values have been measured. Figure 3 shows the resulting hardness values linked to the heating temperature for an exemplary holding time of 6 s and a heating rate of 100 K/s. Heating below 980°C clearly leads to low hardness values due to the incomplete austenitization. Heating above 980°C results in the desired material hardness with values higher than 500 HV10. Based on these results the heating parameters were chosen.

In order to analyze the forming process, a three-dimensional thermo-mechanically coupled FE-model was set up in Simufact.forming (Figure 3). The process sequence has the following structure: The sheet metal strip (initial temperature 20 °C) is locally heated to 1000 °C through inductive heating right before being inserted in the forming tool and is subsequently shaped into a U-profile. After forming, the material is cooled by means of forced air cooling. The heat transfer from the inductor to the sheet was determined through numerical identification. For this purpose, the heat transfer was numerically identified by means of experimental heating tests on a sheet metal strip. The numerical model of the air cooling was obtained in analogy to the heating. The forming material parts were modeled as non-deformable bodies with heat conduction. The discretization of the plate was carried out with solid-shell-elements with an edge length of 2 mm. Four elements are modeled over the thickness of the sheet. The modeling of the sheet conduction or the sheet motion, respectively, is decisive in the representation of a real forming operation within an FE model, in order to generate a realistic numerical simulation model. In order to reach this aim, the real constraints involved in the profiling process in draw bending have to be represented through virtual boundary conditions that are as close to reality as possible. For this purpose, the tensile motion transferred from the clamshell over the fixing point to the sheet and the simultaneous seizing have to be modeled. The tension applied to the sheet by the clamshell in practice, is modeled by two plates holding the sheet from above and below and pulling it, so that the shift of the blank in z-direction is implemented. Simultaneously, the clamshell fixates the sheet in the area of the fixing point, thus facilitating the exact guidance of the sheet. A translational motion in y- and x-direction is prevented in order to reproduce the clamping. In addition, a guidance of the sheet was modeled, in order to prevent the sheet from shifting in x- and y-direction. The description of the friction between tool and sheet was described by Coulomb’s friction law. The initial microstructure distribution was determined with the aid of microstructural analysis and as a result the values of 70 % ferrite and 30 % pearlite were set for the simulation. The flow properties of the sheet are described based on temperature-dependent and strain rate-dependent flow curves for martensite, austenite, bainite, ferrite and pearlite. The calculation of the structural transformation which takes place due to the austenitization and the subsequent cooling of the material is carried out based on a CCT-diagram implemented in Simufact.forming. A realistic calculation of the draw bending operation with integrated heat treatment requires a temperature-dependent modeling of further mechanical and thermal dimensions, such as thermal expansion, thermal capacity, heat conductivity, transverse contraction and elastic modulus. The physical parameters required for the modeling were taken from the database of Simufact.forming v12.

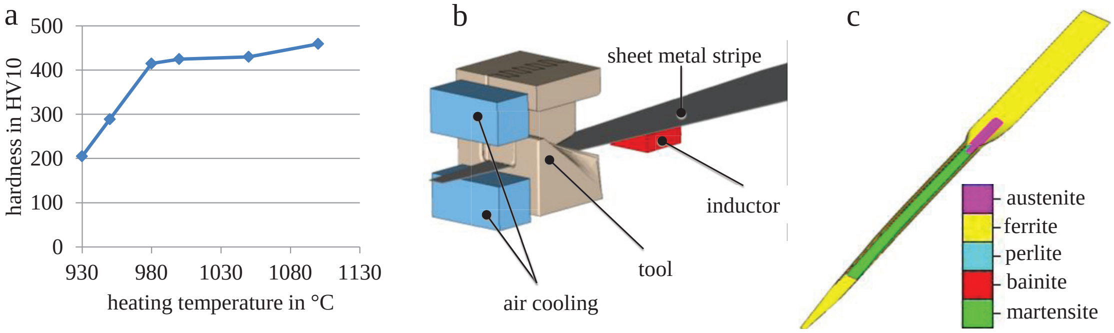

Fig. 3: (a) results of the hardness values linked to the heating temperature with a holding time of 6s, (b) FE-model of the draw bending process with heat treatment and microstructure distribution within the profile (c) [15]

3. Results

In the tests, at first only the bottom area of the sheet has been heated inductively and the temperature has been measured in this area. The measured and the calculated temperature curves from numerical simulation are compared in figure 4 (a). The temperature has been measured during heating, transfer and cooling in the tests. Within the simulation, an element in the middle of the sheet metal has been chosen, which undergoes the whole process. The comparison of the simulation and the experimental results shows a very good accordance of the temperature curves. Figure 4 (b) shows the hardness values of 22MnB5 in the initial state and after the heat treatment during draw bending in the simulation and the tests. In the initial state, the sheet metal has a hardness value of about 155 HV10 at the surface. This value will be tripled by the heat treatment to a value of about 500 HV10. The discrepancy in the tests has been 26 HV10 across the measuring length of the hardened area. The comparison of the simulation and the preliminary tests has shown a very good accordance of the investigated characteristic values at 10 measurement points across the whole length of the U-profile. The analysis of the temperature and hardness curves of the components, the numerical simulation and the experimental tests in the bottom area of the component proved the functionality of the process chain, which has been expanded by the heating of the whole component in the following section.

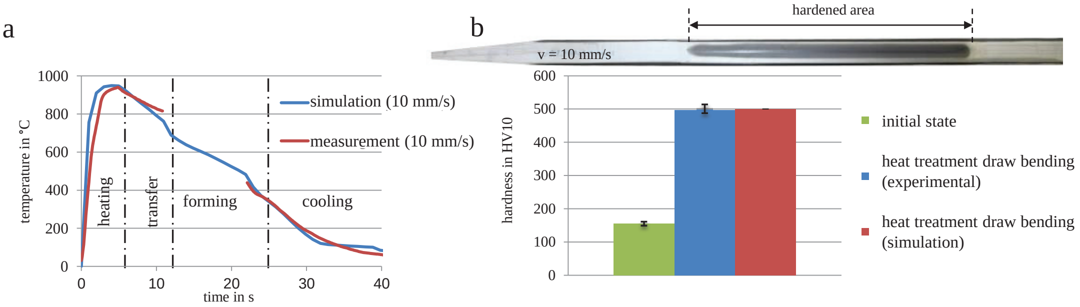

Fig. 4: (a) comparison of the calculated and measured temperature curve of the process [15], (b) hardness values of the initial state and the experimentally an simulatively investigated hardness

This novel process should present the manufacturing of demonstrator profiles in U-shape and the evaluation of temperature profiles, mechanical properties and geometrical accuracy. The heating of the whole sheet with a thickness of 1 mm has been carried out by induction. The temperature has been observed with a calibrated pyrometer at four measuring points.

Figure 5 (a) shows the temperature at the four measuring points located at the inductor, right in front of the forming tool, after forming and after cooling by compressed-air jets. Furthermore, there is a temperature curve of a drag measurement, which shows the single stages of heating, transfer, forming, cooling by compressed air and residual cooling at ambient air. For this, a thermocouple has been welded to the board to measure temperature values during the complete process. This measurement has also been useful to verify the values generated by the pyrometer at the four measuring points. The austenitization of the material at a temperature above 1000 °C with a heating rate of more than 100 K/s and a cooling rate of more than 27 K/s points to a hardening of the profiles, which will be proven in the following hardness investigations. Figure 5 (b) shows the temperature distribution within the board in the heated state by means of thermography. The upper edge of the board has a homogeneous temperature distribution with a value of about 1000 °C. In the picture, the board will be drawn directed to the top. In this direction, the temperature of the board continuously rises.

Geometric accuracy of the components is a main criterion to evaluate the newly developed process chain. By means of the measuring system ATOS of the company GOM, components were measured optically and compared to the other components. The comparison of the components manufactured with the same process parameters should prove the reproducibility of the components. Figure 5 (c) shows the results of the optical measurements of two components compared to each other. The maximum deviation of the components has not been reproducible at the same place. The highest geometrical deviation of the profiles will therefore be investigated on the basis of all profiles. The highest geometrical deviation of 0.87 mm, portrayed in red, has been observed at the profiles with a sheet thickness of 1 mm (Figure 5 c on the right side). The maximum geometric deviation of the profiles with a sheet thickness of 1.25 mm (Figure 5 c on the left side) has been around 1.1 mm at the end of the profile. These deviations are caused by springback effects at the end of the profile. Considering the whole profile, there is a good reproducibility of the resulting shape/geometry. The investigations proved, that the geometrical deviations of the draw bending profiles were below one millimeter in total. The resulting advantages over cold forming are lower forming forces, higher deformability, high dimensional and contouring accuracy, low elastic rebound as well as reduced residual stresses. The hardness has been investigated at the surface. The hardness measurement results have been above values of 450 HV10. This shows that a total transformation from austenite to martensite has been achieved within the process.

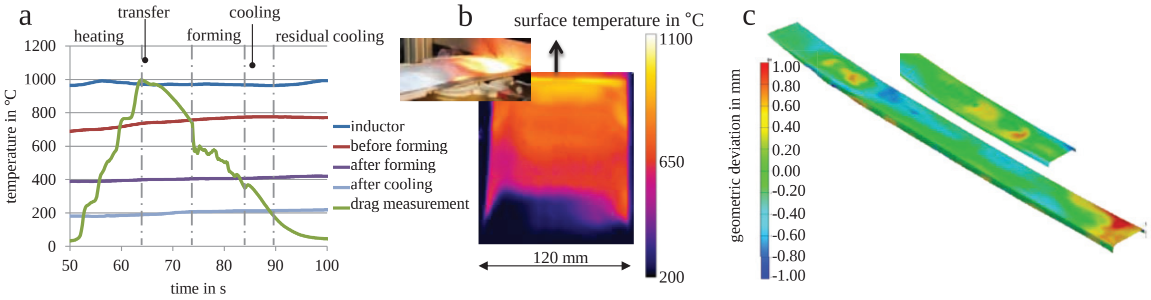

Fig. 5: temperature distribution during heating, (a) time-temperature profile by pyrometers and drag measurement, (b) temperature distribution measured by thermography above the inductor (c) Geometrical deviations of two profiles measured by means of GOM ATOS, on the left: 1,25 mm sheet thickness, on the right: 1 mm sheet thickness

4. Summary

Draw bending combined with inductive sheet heating and subsequent cooling represents a cost-effective and economic concept for producing hardened profiles. After numerical process design, the existing draw bending machine of the IFUM was expanded by an inductive heating unit and a cooling unit. First, experiments on the implementation of a heat treatment during draw bending were carried out with this machine. In the course of these experiments, the process limits reached were recorded based on the required drawing force, the temperature courses in the process and the reached hardness values. These values were used in order to evaluate and validate the results of the numerical simulation. By means of heating the material before it enters the forming die, it has been shown that it is possible to form super high-strength profile components through draw bending. The material was heated to austenitization temperature by a surface inductor and cooled by means of the draw bending tool and compressed air. The material used was a manganese-boron steel 22MnB5 with a sheet thickness of 1.25 mm and 1 mm. Good results were obtained with regard to process and part quality with the aid of an upstream heating. The subsequent comparison with simulation also showed a high degree of similarity and consequently confirmed the results of the numerical simulation of the process. The general feasibility of integrating a heat treatment in a draw bending operation was successfully proved.

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