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ScienceDirect

Procedia Manufacturing 15 (2018) 1095–1102

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

17th International Conference on Metal Forming, Metal Forming 2018, 16-19 September 2018, Toyohashi, Japan

Investigation of masking concepts for influencing the austenitization process during press hardening

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Abstract

One possibility to adjust tailored properties in hot stamping is the application of a masking concept to prevent a complete austenitization. In this study different concepts were investigated in order to use them as a suitable masking. A simulation model of the heating phase was developed for the purpose of predicting the resulting microstructure and hardness. Experimentally determined temperature profiles were used for the numerical model. The numerical results of the temperature profile and hardness were validated by experimental investigations and non-destructive hardness measurements. The simulated hardness is in adequate agreement with the measured hardness.

Keywords: Hot stamping; Partial hot stamping; Masking; Tailored properties; Simulation

1. Partial hot stamping

Various methods for adjusting specific properties of hot stamping components have been examined yet. A known example is the tailored tempering, where the hot-stamping-steel is quenched by different cooling rates by means of a tempered forming tool. In [1] the systematic adjustment of local properties during the direct hot stamping process route of a b-pillar was examined. The used tool contains both heating as well as cooling devices in order to obtain

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10.1016/j.promfg.2018.07.382

transition areas. A more comprehensive overview of different methods for the local adjustment of different ductilities in hot stamping can be found [2].

The influence of the components temperature within the oven is another method for local adjusted properties. The current study refers and presents methods of partial hot stamping by means of using a mask, which are already known and practically applied. In [3] the heat flow of the lower area of a b-pillar is prevented by insulated materials. This procedure avoids the austenitization, thus ductility and forming properties are increased. The usage of masking during the heat treatment in the oven is described [4], which have almost the final shape of the hot stamping component and consists of a multi-component shell structure. Furthermore, it is suggested to apply metals, ceramics or heat-resistant fiber materials as masking materials. On the basis of the known investigations simulation models are developed in current research activities, which predict the local different mechanical characteristics of the hot stamping component. In addition, the model offers the possibility to design the masking adequate with regard to the required properties of the component.

1.1. Modeling of hot stamping

In the heating phase the sheet is positioned in the oven. During the heating phase the ferritic-pearlitic microstructure of the specimen changes to an austenitic microstructure, therefore the thermal field and the microstructural field has to be considered in the simulation. The thermal conditions of the oven must be properly modelled in order to predict the temperature profile precisely. The temperature rate strongly depends on the heat input which is mainly defined by the furnace environment. The heat flow contains convective, radiative and conductive heatflows.

In the simulation of hot stamping, the simulation model is subjected to high requirements due to strong temperature changes. Here, in addition to the mechanical consideration, as in normal deep drawing processes, the thermal interactions between the sheet and tool must be considered as well [5, 6]. The microstructure of the material has a strong influence on the material properties and is highly dependent on the temperature history. Complicated interrelations between the different fields i.e. mechanical, thermal, and microstructural fields have to be taken into account for a model of the hot stamping process, which is close to the reality [7]. The main focus of the standard hot stamping simulation have been put on the cooling phase, in which the microstructure changes from austenite to bainite, ferrite, pearlite and martensite. The forming processes of these phases are mainly diffusion controlled and can be described by different models [7]. A well-recognized approach, which deals with a phenomenological approach and assumes a constant temperature in time, was developed by JOHNSON, Mehl, Avrami and Kolmogorow [8]. Based on the model by Kirkaldy and Venugopalan the authors of [9] developed a model, in which the fraction of the single constituent is dependent on the temperature, austenite grain size, steel composition and the activation energy of the different phases. It differs from the Kirkaldy model regarding the influence of the composition and the grain size. The change from austenite to martensite takes place almost instantaneously and is not diffusion controlled. It mainly depends on the magnitude of undercooling.

A predominant part of models assume a totally austenitic microstructure in the beginning. When dealing with hot stamping the heating phase is normally neglected. In cases where the assumption of 100 % austenite is invalid, the actual amount of austenite must be considered, e. g. in welding operations [10, 11]. In the model of [12] the average growth rate of a spherical volume of austenite is strongly dependent on the characteristic time, which depends on the overheating of the perlite phase and has a crucial influence on the forming of the austenitic phase. The model was able to predict the experimental results, in which the specimens were kept at a constant temperature. When AC_1-temperature is exceeded the iron carbides transform to a eutectoid austenite. A model accounting for the both partial austenitization under intercritical annealing, and complete austenitization in continuous heating as well as the holding time was developed by [13]. The model properly reproduces the experimental results for the heating and holding phase.

2. Experimental setup and procedure

For the selection of an adequate masking concept, the first step is to test the preselected materials for their suitability. The dimension of masking is varied in case of thickness and used materials. This experimental procedure includes the placing of boron steel 22MnB5 sheet metals with AlSi (aluminum-silicon) coating into the oven and heating them up. The dimensions of the used 22MnB5 sheet metals were 220 mm x 140 mm with a thickness of 1.5 mm. In order to ensure sufficient diffusion time for the coating the heating time should be five minutes with a temperature of about 950 °C [14]. After the recommended time in the oven, the masking is removed and the sheet is subsequently quenched by a cooled forming tool. The objective of the examination is a quantitative optical analysis of 22MnB5 sheet metals as well as the masking during the process route, a qualitatively evaluation of the different temperature zones and an investigation of the resulting hardness.

The examinations were carried out on a hydraulic press (type: Hydrap HPDZb 63), which pressed the sheet metals for 9 seconds with a pressure of 2.44 N/mm². To determine the temperature during the process, sheath thermocouples were inserted in the masking and the sheet metal (section 3.1). The experimental setup is illustrated in Fig. 1.

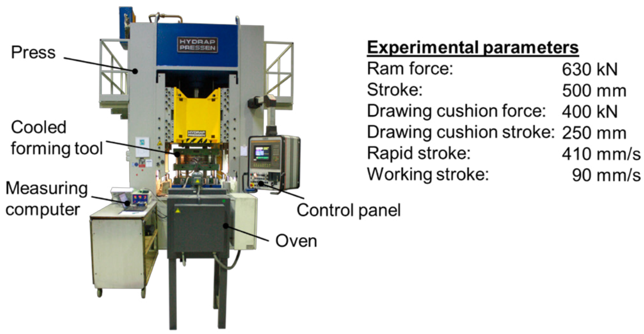

Fig. 1. Experimental setup and parameters.

Then the masking concept is realized by mounting stripes with the dimension of 140 mm x 50 mm on the sheet metal. The masking was fixed in the middle of the 22MnB5 sheet metals as shown in Fig. 2. During the selection of adequate masking materials the following criteria and requirements were considered:

- Low thermal conductivity
- Convenient handling
- Reusability
- Diffusion of the AlSi coating
- No chemical bonding between masking and sheet metal

Three different materials were found to fulfil these requirements: porcelain stoneware, thermal insulation and ferritic stainless steel. The material porcelain stoneware features a low water content of < 0.5 % [15]. During the manufacturing process (sintering) it is subjected to high burning temperature of over 1250 °C. The thermal insulation panels have a thickness of s_0 = 2 mm and a temperature resistance of 1000 °C. The third considered material is ferritic stainless-steel X2CrTiNb18 with a thickness of s_0 = 1 mm, which features a heat resistance over 900 °C [16] and is furthermore used in exhaust areas [17].

In preliminary test the material porcelain stoneware proved to be unsuitable due to the formation of cracks during the subsequent cooling phase at approximately 600 °C. Therefore, only the thermal insulation panels and the stainless steel were used during the further examinations. The masking material X2CrTiNb18 was varied according to the number of stripes and the thickness. Some of the applied variations are shown in Fig. 2.

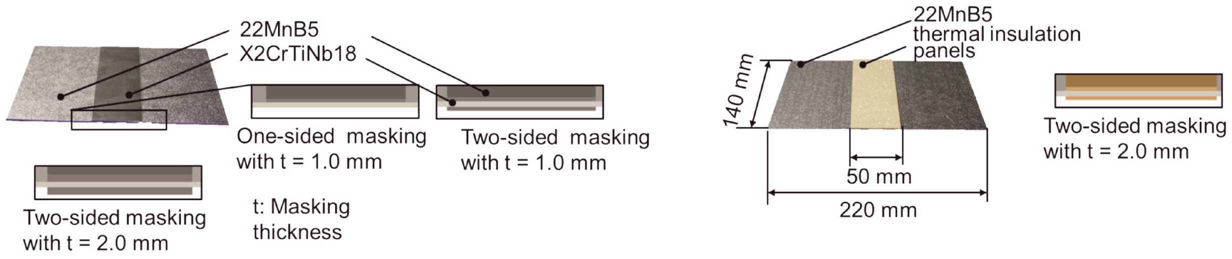

Fig. 2. Variation of masking of stainless steel X2CrTiNb18.

3. Analysis and results

In this chapter, the results of the investigations for the selection of a suitable masking (dimension, material) are presented, which are based on the aforementioned preliminary experiments. Furthermore, the examinations were utilized for determination of boundary conditions that could be applied in the numerical simulation. Subsequently, a simulation model of the heating phase was developed to enable a process-oriented masking design. The simulated hardness was correlated to experimental hardness measurements.

3.1 Determination of simulation parameters

Previously conducted investigations showed that cooling on different heating temperatures at a constant cooling rate resulted in different hardness of the sheet metals. Based on these results, a masking should be selected, which keep the covered masking area below the required temperature during the holding time in an oven. The covered masking area is called joining zone in the following. The sheath thermocouples with a diameter of 0.5 mm were inserted into the sheet metal and the masking (depth: 10 mm). The position of the thermocouples and the recorded temperature profiles are shown in Fig. 3.

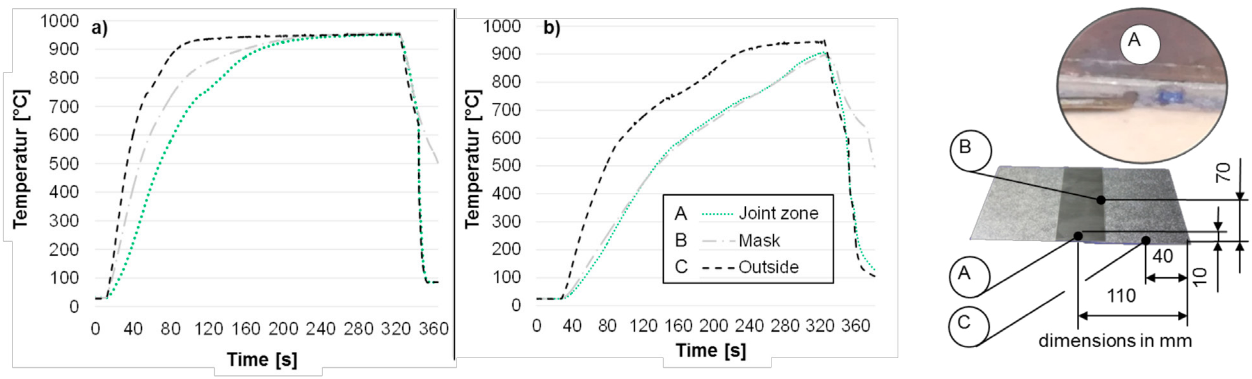

Fig. 3: Temperature measurement on two-sided masking (X2CrTiNb18); a) 1 mm thickness, b) 2 mm thickness

The joining zone of the one- and two-sided masking variants, each with 1 mm sheet thickness, could inadequate be insulated in the measured area. Thus, it is assumed that there is an insufficient hardness decrease in the core of the joining zone due to inflowing heat. In contrast, a two-sided masking with 2 mm sheet thickness had a temperature difference of about 50 K. The characteristics (cooling and heating rate, thermal conductivity and temperature differences between / within each zones) determined from the temperature profiles were used as input parameters for the simulation model.

3.2. Simulation of heating process

For the purpose of determining the microstructure the heating process must be examined. In order to analyze the temperature distribution in the sheet and thermal insulation a two dimensional section of the sheet is taken (see Fig. 4). Hereby it is assumed that the temperature distribution is symmetric to the zy-plane, xz-plane, assuming that the heat is solely entering from the top and bottom into the sheet. Edge effects are neglected.

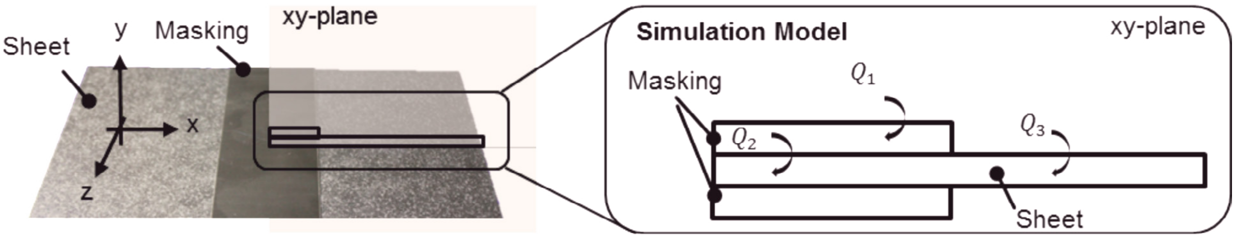

Fig. 4. Simulation model of heating process.

A proper prediction of the microstructure is based on a precise temperature field analysis. The temperature field in the sheet is dependent on the heat fluxes from the oven environment over the thermal insulation and the free surface into the sheet. Therefore, capturing the heat transfer is important. The heat transfer is composed by a radiative heat transfer and convection, which are acting at the same time. In order to determine the heat transfer the recorded temperature time curves have been used in combination with a lumped parameter model, which reduces the complex initial boundary value problem to a set of two differential equations. The respective heat transfer coefficients were determined by fitting the heat transfer coefficients to the temperature time curves. A temperature dependent convection coefficient was determined, combining the radiative heat as well as convective heat input.

The computed heat coefficients of the lumped parameter model were transferred to an FEM-simulation model of the experimental process. In Fig. 5 the spatial temperature distribution after heating and the temperature evolution in hree points over time are shown for the mask on side. The temperature-time lines are compared to the experimental results. The obtained results properly approximate the experimental results.

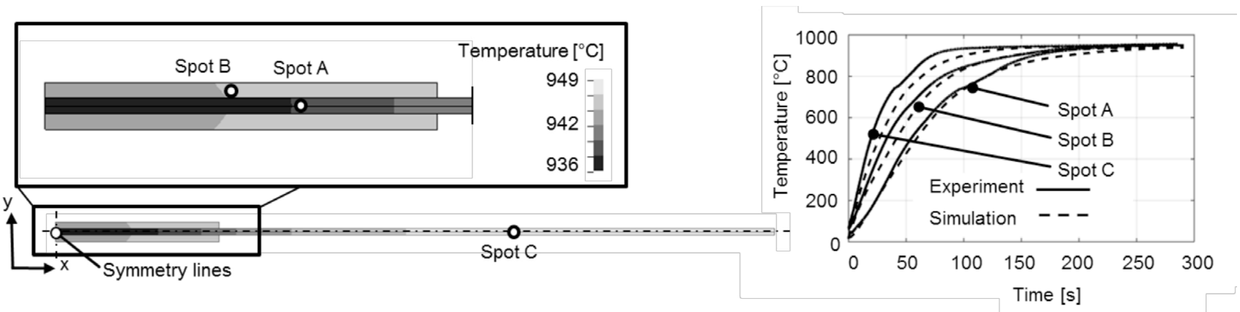

Fig. 5. Temperature distribution after 300 s and temperature-time distribution in marked spots.

The masking concept is limited by the heat flows from the free surface of the sheet into the covered regions. Due to these heat flows a large transition area is created, in which a mixed microstructure of austenite and perlite is created. When a single mask is used the temperatures in the masked region exceed the AC_3 temperature significantly. The amount of austenite formed in in the sheet is dependent on the local temperature time profile and is shown for both masking concepts in Fig. 6. None of the masking concept is able to prevent the austenitization of the microstructure. Especially the heat input from the sides renders the presented masking concept for small regions as unsuitable.

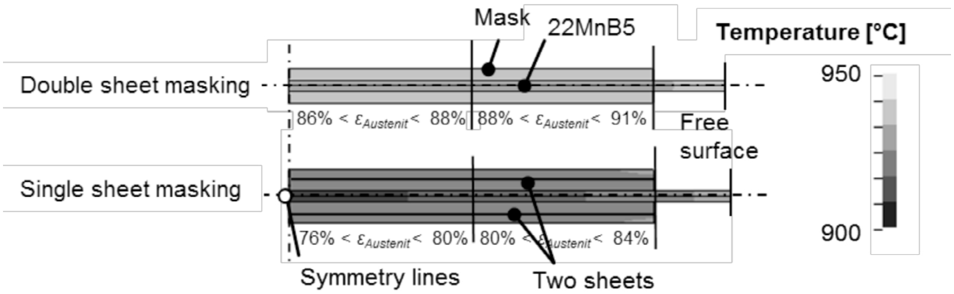

Fig. 6. Temperature distribution in sheet after 300 s of heating by using single and double sheet on both sides as mask.

In the examination it was shown that the examined masking concept is insufficiently qualified to properly prevent the austenitization of small regions. Furthermore, the region, which is affected by the heat flow from the uncovered regions, is too large in order to derive the full potential. Therefore, in a second approach the masking concepts are experimental tested and simulated for a larger masking region.

The larger concepts are simulated as well. The cooling phase in the tool is included in the simulation regarding to determine the microstructure. A critical cooling rate is obtained in all regions, which causes a transfer from the austenitized regions to martensite. In order to carry out the investigations with larger sheet metals (dimensions: sheet metal 480 mm x 250 mm, masking 250 mm x 150 mm), the experimental setup was changed and the test parameters were adapted accordingly. This changes the thermal conditions. To consider the different environments the heat transfer coefficients from the oven to the sheet had to be reduced. It could be determined that the scaling effects have an influence. Therefore, the parameters of the simulation have to be adjusted.

To validate the simulation results, the most appropriate dimensioning of the masking was examined both quantitatively optically and qualitatively by means of a non-destructive hardness measurement. The masking in form of thermal insulation board was evaluated as not suitable regarding to the designed component and the masking geometry, since there was no complete diffusion of the AlSi coating.

An examination of two-sided masked sheets with different thicknesses were further analyzed, see Fig. 7. Optically it could be determined that in cases of a 1 mm thick masking, the hot stamping sheet metal has a larger transition zone. In addition, the shape of the joining zones is conical. This conical form is less pronounced when a two-sided masking with a thickness of 1 mm is used. This is presumably due to a slighter absorption of heat by the masking. Non-destructive hardness measurements by means of the 3MA (Multi-Parameter Micro-Magnetic Microstructure and Stress Analyzer) measurement system show the effects on the material-specific properties of the 22MnB5 depending on the masks used within the joining, transition and outside zones. Thus, a maximum hardness drop of 279 HV between the edge zone and the joining zone could be determined when using a masking with a thickness of 2 mm. Nevertheless, the transition zone shows a hardness of approximately 390 HV for both masking thicknesses and thus differs clearly from the joining zone.

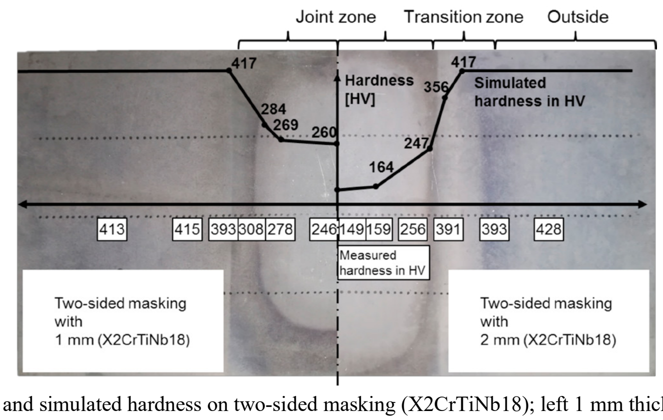

Fig. 7. Hardness measurements and simulated hardness on two-sided masking (X2CrTiNb18); left 1 mm thickness; right 2 mm thickness.

4. Summary

In this study experimental investigations were performed in order to adjust tailored properties in hot stamping components by means of different masking concepts. Different materials and thicknesses were used for the masking. The characterization of the material with regard to the resulting microstructure and the determination of the temperature profiles during hot stamping process route were used as input parameters for the development of a simulation model of the heating process. A validation of the simulation was carried out on the basis of experimental investigations and the subsequent non-destructive hardness measurements of the components. Based on the model, an optimal masking zone could be determined with an approximately accurately prediction of the resulting hardness.

5. Outlook

The mechanical and thermal joining of hot stamped parts is limited due to the high hardness and increased yield strength. By the specific adjustment of locally varying mechanical properties, this problem could be solved. In order to adjust areas with lower strength, a separate cooling device (spray field) in combination with a masking concept is used between the austenitization procedure in the oven and hot stamping process. The cooling device should cool down certain sheet areas while other regions remaining at higher temperature and thus ductile joining areas are created. The basic scheme is shown in Fig. 8.

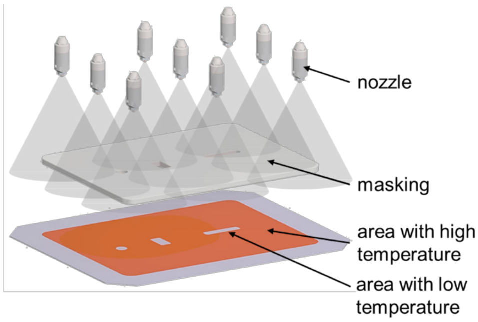

Fig. 8. Basic concept for adjusting different temperature areas on a sheet metal.

Investigations with a quenching and forming dilatometer reveal the effect of a pre cooling, which could be realised with a cooling device (spray field). Table 1 gives an overview of the used temperature-time profiles and the resulting hardness for the different heat treatments.

Table 1. Temperature management of heat treatment process and resulting hardness of specimens (material: 22MnB5, thickness 1.5 mm).

	Option 1	Option 2	Option 3	Hot stamping
Heating in oven	Heating from 20 °C to 930 °C in 180 s +			
	Holding temperature (930 °C) for 180 s			
Cooling device	Cooling from 930 °C to 600 °C in 20 s	Cooling from 930 °C to 500 °C in 20 s	Cooling from 930 °C to 500 °C in 30 s	Holding temperature (930 °C) for 20 s
Transfer (5 s)	From 600 °C to 570 °C	From 500 °C to 478 °C		From 930 °C to 850 °C
Quenching (10 s)	From 570 °C to 150 °C	From 478 °C to 150 °C		From 850 °C to 150 °C
Hardness	**391 HV30**	**362 HV30**	**259 HV30**	**457 HV30**

The heat treatment options 1-3 represent potential pre cooling options for creating ductile joining areas. To enhance comparability, the conventional temperature management of a hot stamping process was simulated. An average hardness of 457 HV30 was determined for these specimens. The heat treatment options 1-3 indicate that reduced cooling rates result in a higher ductility, is obvious by the hardness decrease. The hardness measurements confirm that pre cooling, e. g. with a cooling device (spray field) as shown in [18, 19], is suitable for adjusting different mechanical properties. The use of a cooling device offers the possibility for improving the joining properties of hot stamped parts. In further investigations a numerical process simulation will be done to determine the locally required cooling rates, which will be validated with hot stamping related investigations. Based on this a cooling device is designed and experiments with a new hot stamping process route are carried out.

Acknowledgements

The presented work is a result of the projects „Production of areas with reduced strength in press-hardened components by means of a tempering station“, project number BE 1691/203-1, and „Press hardening using masks during furnace process for partial austenitization“, project number BE 1691/200-1.

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