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Hot stamping of load adjusted structural parts

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Abstract

The importance of high-strength steel concepts for car bodies has increased in recent years due to the necessity of weight reduction and improved crash safety. By using hot stamping or also known as press hardening of boron alloyed heat-treatable steels, it is possible to produce parts with a much higher strength than by cold forming processes. Depending on the stress profile of a structural part, it might be desirable to have different material rigidity in the part, with some high strength and other more ductile areas, so called "Tailored properties". There are a variety of methods to produce such parts, but all of these methods have currently still major challenges. Two methods to manufacture parts with tailored properties, these challenges and corresponding approaches are presented in this paper. This is on the one hand subsequently cooling in a spray field, which currently is still in the development phase because of challenges related to distortion. And on the other hand, the masked austenitization, which is used by only a few manufacturers due to the lack of experience, the impairments of coating condition and the great demands on the process management concerning re-cooling of the mask. Both variants are forward-looking and deliver high potential for further research.

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Keywords: Hot stamping; Press hardening;Tailored properties; Spray cooling; Masked austenitization

1. Introduction

A technology to manufacture highest-strength automotive parts is hot stamping also known as press hardening. This process combines forming and heat treatment of sheet metal material. In industrial production, hot stamping is

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carried out in two variants, direct and indirect. In the direct process, which is used in the frame of these investigations, forming and heat treatment are carried out in a single step. At the beginning of the process a shaped blank of boron alloyed heat-treatable steels, e. g. 22MnB5 (1.5528) is heated up to a temperature of about 950 °C to achieve austenitic microstructure. Afterwards it is formed with a cooled punch to quench the blank and to get ultra-high strength martensitic microstructure with values of more than 1500 MPa. The fracture strain of these parts lies within the range of 5 - 7 % (Karbasian et al., 2012; Mori et al., 2009).

Depending on the stress profile of a structural part, it might be desirable to have different material rigidity in the part (Fig. 1).

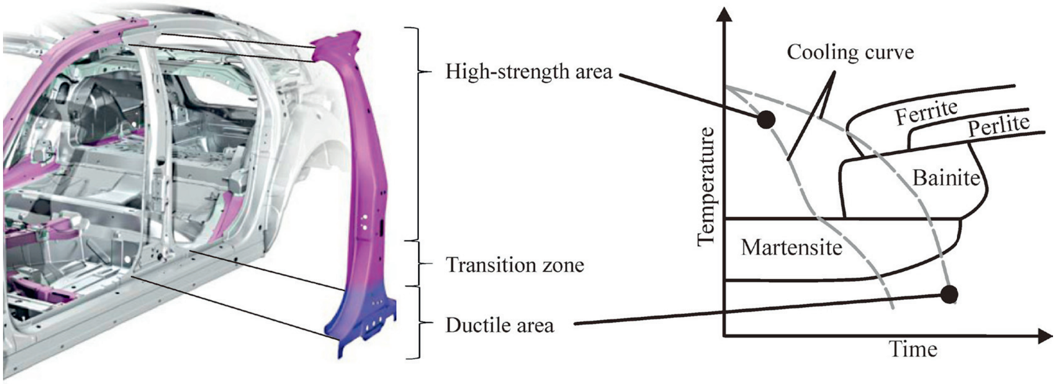

Fig. 1. B-pillar with tailored properties (Wilde, 2011) achieved through different cooling strategies.

To manufacture parts with so-called tailored properties, tailored blanks are required. Tailored blanks are customized semi-finished parts what enables a local adjustment of the future part previous to or during production, through targeted modifications in the production processes. The areas of the drawn part which are exposed to high loads become reinforced by means of increased material strength or thickness whereas those areas that are less strained and the connection zones require less material strength and thickness. Thus, a reduction of the part weight with retained or even improved functionality and strength is possible. Today various process strategies exist to produce parts with tailored properties. In addition to the local adaptation of the sheet thickness and other structural solutions, such components may also be generated by setting diverse material behaviour by different micro structural states (Stöhr et al., 2009): Only martensite in areas with high loads and a mixture of ferrite, bainite and martensite for areas with lower loads or connection zones. Two methods to manufacture parts with tailored properties by means of setting different micro structural states are presented in the following.

2. Tailored cooling in an external spray field

In tailored cooling process strategies, the creation of a fully martensitic microstructure is prevented through differing cooling rates and intermediate structures are generated. They feature lower strength but in return have a higher deformability. Locally different cooling rates in one part can be realized through differing cooling strategies in the subsections of the tool (Maikranz-Valentin et al., 2008). Another option would be, to provide the tool with gaps, in order to obtain areas which do not have bilateral tool contact during the heat treatment (Erhardt et al., 2008). This leads to lower cooling rates in the areas with gaps than in the remaining part areas (Sikora et al., 2012). Regarding this, there are various known approaches on the tool side and some more are subject to current research. During hot stamping, transformations from austenite to other phases are caused. The local material properties of the parts are mainly influenced by the achieved phases and so by the duration of forming and hardening.

Normally, the hardening takes place in the closed die in the press. But press time is very expensive, therefore parts have to be removed as fast as possible in order to increase productivity. But reducing holding time can be associated with impairments of the part quality. Due to an early part extraction from the press the deformation increases. Less holding time in the press causes a higher extraction temperature and deformation. According to the state of the art this problem has not been solved yet. So momentarily the holding time will not be reduced. To reach partial differing properties in a component, the holding time in the press has to be increased caused by heated tools. Because an increase in the holding time should be avoided, a process chain with an abbreviated hot stamping process and component cooling in an external spray field has been developed by the Institute of Forming Technology and Machines and the Institute of Materials Science at Leibniz Universität Hannover.

The objective is to remove the hot component from the tool as soon as possible and to complete the residual cooling outside the press. With differing spray field parameters, component areas should be adjusted tailored to the load. Hot stamped components with partial properties are of high interest in the automotive industry.

First results reveal that the productivity of the conventional process of hot stamping can be increased by applying an early extraction of the parts from the hot stamping tool and a combined external cooling in a spray cooling facility. The mechanical properties can be adjusted in the spray field. Despite the short holding times, it is thus possible to reach mechanical properties with a tensile strength up to 1500 MPa. Partial component properties have also been achieved. First tests with a cap profile geometry have shown a partial cooling is possible by a shortened hot stamping process and a further cooling in a spray field. Fig. 2 shows the hardness profile of a component after a shortened hot stamping process and spray cooling outside the press. The difference between the hard area, with hardness values of up to 530 HV10, and the ductile area, with hardness values of about 300 HV10, can be observed clearly. By adjusting the extraction temperature and the cooling parameters in the spray field partial differing mechanical properties with a hardness gradient of up to 250 HV10 can be achieved. These properties are of high interest in terms of structure components of automotive body parts.

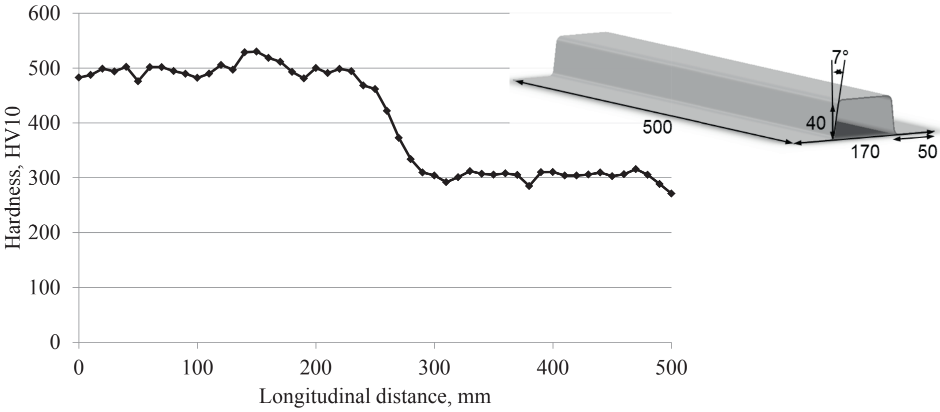

Fig. 2. Hardness profile in a component after shortened hot stamping process and spray cooling.

The results of the cap geometry parts have proved the possibility of manufacturing partial differing component areas by a shortened hot stamping process and cooling in an external spray field. The component properties have been changed approximately in the middle of the part.

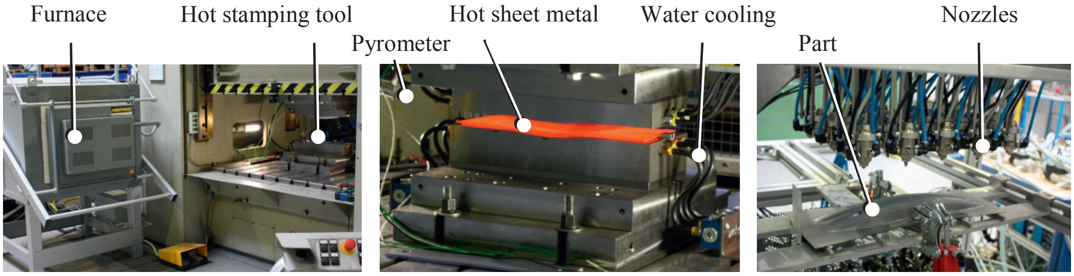

Fig. 3. Experimental setup of hot stamping process with subsequently cooling in spray field.

In further tests the results of the cap profile should be applied to a more complex geometry. The test setup is shown in Fig. 3. A variation of partial properties should for example be achieved in a flange more ductile than the rest of the component. Thus joining or cutting of the component can be improved in marginal areas. Due to the components, the dimensional accuracy, the influence of hydrogen embrittlement and the mechanical properties are investigated.

3. Tailored heating by means of local masking of blanks

After the shown ability to set the tailored properties after forming process due to spray cooling, the second approach is based on the adjustment of the properties during the heating process. Providing tailored heated blanks for processing in hot stamping tools can be well realized in standard continuous furnaces. For producing parts with discretionary low strength areas the austenitization, basis for martensitic phase transformation, has to be suppressed specifically during heating process process (Fernandez et al., 2011). Therefor masking appliances can be implemented in the furnace technology. The masking body should feature an adequate thermal capacity. Thus, it absorbs thermal energy from the blank locally (Sommer et al., 2010). In addition, the masking body surface reduces the heat input to the blank by shielding (Gehringhoff et al., 2008). Fig. 4 shows a blank in a furnace straight after removing a rectangular masking body from its upper surface. The recently masked area features a temperature lower than austenitization temperature. The thermal energy input of the masking body during furnace residence time has to be emitted before next usage. Thus, a re-cooling process is necessary which has been an impediment for original equipment manufacturer production plants until now.

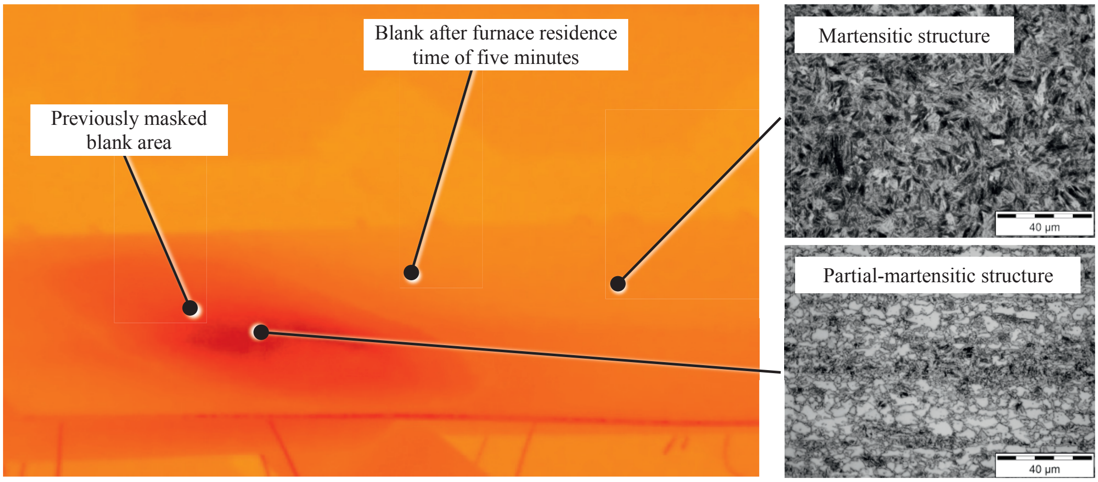

Fig. 4. Blank with specific heat distribution straight after masking body removal and microsections of the subsequently quenched blank.

The shape of the intended low strength areas can be customized through different masking shapes or masking amounts. The mechanical properties can be varied locally by adjusting different austenite magnitudes at the end of heating process. Related to default furnace residence time, the austenitization can be influenced e.g. by different masking body volumes and materials as well as contact surface and shielding surface conditions. Furthermore, the masking body can be spaced to the blank surface. Transition zones can be expanded by progressive gaps.

For the experiment of Fig. 4 the blank with the un-spaced masking body was put in the furnace at 950 °C remained for five minutes. Afterwards, the masking body, consisting of a stainless steel sheet bundle, was removed and the blank was transferred to a planar hot stamping tool which performs cooling rates more than 30 K/s. Fig. 4 shows also selected microsections of the blank after quenching. The specimen from a non-masked area features a full-martensitic structure and has a hardness of 510 HV2 in the mid-plane. In contrast the specimen from the masked area centre has just certain martensitic phase contents. Thus, the hardness is reduced to 310 HV2.

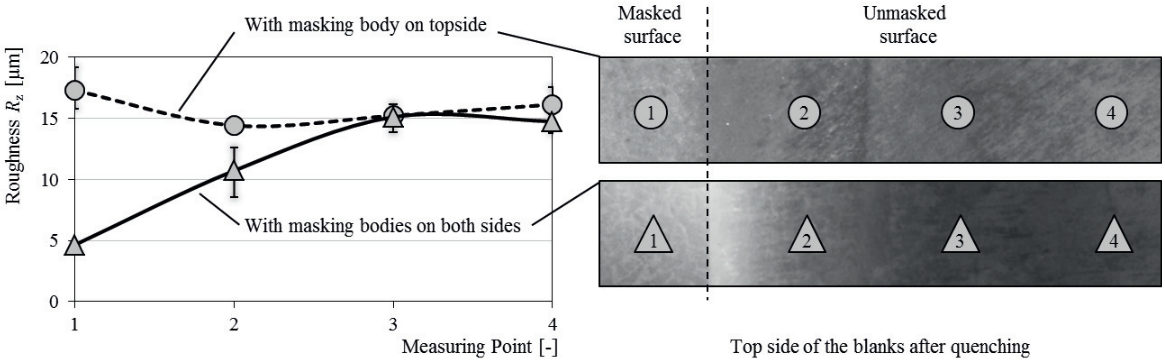

Fig. 5. Roughness coefficients and top view sections of the Al-Si coated specimens after quenching in a planar hot stamping tool.

In addition to the mechanical properties the influence of masking on Al-Si coating has to be observed, too. In general, a certain surface roughness is necessary for a sufficient paint adhesion. Fig. 5 shows the results concerning the coating roughness coefficient and top view photographs from the transition zones. The blanks were provided with a masking body on the topside as well as on both sides, each without any gap between the surfaces. Double-sided masking suppresses austenitization of the steel and diffusion of the coating almost completely. The surface is comparable to the initial state and features roughness R_z about 5 µm which is quite unfavourable for paint adhesion. Even at some distance from the masked area the resulting roughness is impaired. The single-sided masking leads to a roughness coefficient comparable to conventional parts respectively non-masked blank areas.

4. Demands on the numerical simulation due to tailored heating

An effective method for the design of components manufactured by tailored heating is the simulation-based calculation using the finite element method. However, this requires an accurate and preferably complete material model under real process conditions. The compilation of such a model makes high demands on the developer. A necessary material model for the forming and quenching process which take into account both, non-austenitized and partial-austenitized, as well as austenitized areas is currently not state of the art. Most of the current models assume a fully austenitized material at the beginning of the calculation of the deformation and quenching.

However, it is essential to consider the complex effects of phase transformation and their respective characteristics as a function of the austenitization-state after heating in the simulation. Therefore a thorough material characterization has to be performed. On this basis it is possible to analyse the material behaviour based on the austenitization-state for the mathematical modelling and the numerical simulation. The main features to focus on are the flow behaviour with yield locus and yield curves and the microstructure evolution.

For example, depending on the austenitization-state and the temperature, the yield locus which describes the transition from the elastic to the plastic range has a different shape. The use of the same yield locus for all austenitization-states as it is done currently by default, leads to inaccuracies in the numerical simulation. This problem can be met by temperature-dependent and microstructure-dependent yield loci. Thereby, the main challenges are the determination and the consideration in the material model.

The determination of the yield loci of different austenitization-states and temperatures is complex because of the temperature profile with continuous cooling rates of up to 50 K/s based on process conditions. This profile is to be realized with test machines for varying tests under different stress states - layer compression test (biaxial tension), notch tensile test (plane strain tension), tensile test (uniaxial tension), shear-tensile test (simple shear) and pressure test (compression) - to get a sufficient number of supporting points. Conventional test machines do not allow such a temperature control. For this reason a quenching and deformation dilatometer in combination with an optical measurement system comes into operation for which the necessary samples have to be designed specially.

The next challenge is the consideration of these parameters in the simulation, especially by modelling the transition zone with partial-austenitized areas. One approach that is currently being investigated is based on an existing model to predict the microstructure due to the quenching process (Behrens et al., 2008), (Behrens et al., 2013). Based on this model, which was also implemented at the Institute of Forming Technology and Machines an extended approach is developed which calculates the respectively correct austenitization-state for each point depending on the temperature history by a rule of mixture and provide it for the simulation. Therewith it becomes possible to predict the resulting microstructure distribution and component properties.

5. Conclusion

Depending on the stress profile of a structural part, it might be desirable to have parts with tailored properties. Two innovative methods to produce such parts were presented in this paper: the subsequently cooling in a spray field and the masked austenitization. Both provide very good results but have still potential for further research.

By adapting the spray field in the hot stamping process, locally varying mechanical properties can be generated with hardness gradients of up to 250 HV10. Since such properties are of great interest regarding a further joining of hot stamped parts the later processing is still object of current research.

Using masking bodies is appropriate to provide tailored heated blanks for producing load adjusted hot stamped parts. But for a robust masking concept the influences on the coating have to be considered, too. To provide a masking technology suitable e.g. for original equipment manufacturer production processes further studies are necessary for reliable predictions of specific mechanical properties and coating conditions. Furthermore, re-cooling concepts for the heated masking bodies have to be contrived.

Due to the more complex process, however, greater demands are placed on the designer using the finite element analyses. The material models therefore need to be adapted and optimized. This is possible by an accurate material characterization and an intelligent mathematical description. As an outlook a possible approach to realize it was presented at the end. But this is actual state of research and need further investigations and validations.

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