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INVESTIGATIONS ON THE THERMAL BEHAVIOR OF ULTRA HIGH STRENGTH BORON MANGANESE STEELS WITHIN HOT STAMPING

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ABSTRACT: The increasing demand for high strength steels regarding light weight construction design for the body in white is enforcing the automotive industry to onset more and more innovative forming technologies due to the reduced formability of such high strength steel grades. The hot stamping of boron manganese steels is hereby one of the main forming processes to be named. Besides the commonly used forming strategy where a homogeneous distribution of the material parameters is achieved, the partial press hardening is an innovative technology to be able to manufacture parts with a locally different strength and ductility profile. The thermal properties needed for this kind of process strategy had been determined using a heatable quenching tool developed at the Chair of Manufacturing Technology and are further discussed in this paper.

KEYWORDS: Hot stamping, 22MnB5, Heat transfer coefficient, Partial press hardening

1 INTRODUCTION

With respect to light weight construction design in the automotive industry, more and more body parts are manufactured out of high strength steels, which are characterized by a significant thinner sheet thickness but an equal strength as commonly used steels [1]. Regarding higher forming forces of high strength steels, thermal assisted forming technology like hot stamping of quenchenable boron manganese steels gains more relevance. Not all applications require a high mechanical strength throughout the whole component, but in some regions a higher ductility is of great importance to relieve higher forces in case of e.g. crash situation. Therefore new strategies of hot stamping had been developed, the so-called partial press hardening. Hereby tailored mechanical properties are realized in one part and one forming process. The accurate prediction of the thermal behavior is hereby of great importance to be able to control and predict the occurring microstructure as it is liable for the strength. Regarding partial press hardening, the temperature dependency affecting the formability is already state of the art as it is equivalent to the approximation of the temperature dependent mean true stresses attained for commonly applied hot stamping, as is the determination of the frictional properties for the forming of the high strength steel 22MnB5 [2, 3]. The determination of the cooling behavior with respect of different tool temperatures still has to be investigated and will be therefore subject in this paper.

2 HOT STAMPING OF BORON MANGANESE STEELS

Hot stamping, also known as press hardening, is an innovative, non-isothermal hot sheet metal forming technology, whereby austenitized blanks are formed and quenched simultaneously in one process step. The commonly used sheet metal material in the automotive industry is hereby the boron-manganese steel 22MnB5 with respective sheet thicknesses between 0.8 mm and 2.5 mm. Within hot stamping the steel passes a two step microstructural transformation from ferrite-pearlite into austenite by means of a specific heat treatment followed by a martensitic phase transformation during quenching in the stamping press. Thus it is possible to realize parts with a strength up to 1600 MPa as well as with complex geometric shapes due to the enhanced formability caused by reduced flow stresses at elevated temperatures. Currently hot stamped parts find their application as crash and safety relevant components in the body in white (BIW) at almost every main car manufacture in the world [4]. Within the hot stamping process a flat blank is heated up in a furnace, homogeneously austenitized at a temperature above the material specific Ac_3-temperature of approximately 850 °C transferred to the press by robotic feeding systems and subsequently formed and quenched in one process step in the press. The temperature window for the actual forming process within the die is limited to the austenitic state of 22MnB5 which is a result of the martensitic phase transformation during the hot stamping process. Due to

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the martensitic start temperature (Ms) of the material at approximately 400 °C [5] and the transfer dependent cooling of the blanks on air from the furnace to the tool, the forming of the blank usually takes place in a temperature range between 850 °C and 600 °C. Besides the two main strategies of this process, the direct and indirect hot stamping process, a new forming strategy is currently under investigations, namely the partial press hardening. The goal of this strategy is the manufacturing of blanks with tailored mechanical properties, whereby regions of the part do not show a fully martensitic microstructure, but a multiphase microstructure which causes a higher desired ductility. This can be achieved in two different ways: on the one hand by a not complete austenitization of the semi-finished product, realized through repressing in the furnace, and on the other hand by lowering the respective cooling rate under the requested 27 K/s, which would be essential to achieve a fully martensitic microstructure. With regard to the second point a solution to reduce the cooling rate could be to heat the tools or to establish defined gap distances. To characterize the thermal behavior of the blanks and to provide appropriate characteristics for the FE modelling of such processes, a heatable quenching tool had been developed enabling the determination of tool temperature dependent cooling rates and heat transfer coefficients.

3 INVESTIGATED MATERIAL

As material for the presented quenching tests the boron manganese steel 22MnB5 had been applied, which represents the commonly used high strength steel for the manufacturing of hot stamped parts in the automotive industry. The initial sheet thickness t_0 had been 1.75 mm, with the base material coated with an aluminium silicon layer. In the initial state, the material exhibits a fine grain ferritic-pearlitic microstructure with a good formability, hereby the yield and tensile strength are characterized by values of about 400 MPa and 600 MPa respectively. After the heat treatment and the subsequent forming and quenching operation the strength is increasing to about three times higher values. This transformation is caused by a martensitic phase transformation, requiring a minimum cooling rate of 27 K/s. In contrast to that, for the partial press hardening a bainitic or austenitic-bainitic multiphase microstructure is desired to realize a more ductile mechanical behavior.

4 DETERMINATION OF THE HEAT TRANSFER COEFFICIENT

4.1 EXPERIMENTAL PROCEDURE

For the determination of the heat transfer coefficient under process relevant conditions, a quenching tool (Figure 1) had been constructed at the Chair of Manufacturing Technology, implemented in a universal mechanical testing machine type SchenckTrebel RM400 with a maximum normal force of 400 kN. This testing device enables a pressure capture up to 40 MPa to the chosen geometry of 58 x 160 mm². The tool mainly consists of two exchangeable, heatable contact plates, whereby rectangular, thermocouple equipped specimens are placed on four adjustable spring-seated pins. The pins prevent the previously at various temperatures of 860 °C up to 950 °C austenitized blanks from a too distinctive cooling before the quenching operation takes place.

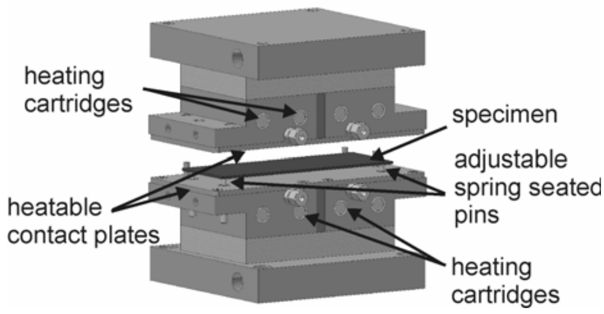

Figure 1: *Schematic exposition of the quenching tool with integrated heating cartridges*

Eight integrated heating cartridges enable the temperature adjustment of the tool up to 600 °C for the determination of tool temperature dependent heat transfer coefficients. Different gap distances have been realized by inserting appropriate templates. Moreover the tool is devided in four different temperature zones, which enables the determination of according heat transfer coefficients and the arising distribution of the microstructure regarding partial press hardening.

4.2 ANALYTICAL CALCULATION OF THE HEAT TRANSFER COEFFICIENT

With the before mentioned thermocouples, the temperature can be measured and recorded online throughout the whole quenching operation. According to Newton's cooling law (Equation 1) the heat transfer coefficient can be subsequently calculated.

$$T(t) = (T_0 - T_u) \cdot e^{-\alpha \cdot \frac{A}{c_p} \cdot t} + T_u \qquad (1)$$

Regarding the equation, T_0 and T(t) indicate the initial and the actual temperature of the specimen during the quenching tests. A quantifies the geometric contact surface, t the respective time and c_p the effective heat capacity [3]. As all parameters can be measured according to the experiment, the heat transfer coefficient α is the only unknown parameter. Taking different tool temperatures T_U into account, a comparison of the individual cooling behavior can be discussed. For the investigations presented in this paper, heat transfer coefficients for tool temperatures of 20 °C, 100 °C and 300 °C had determined. Furthermore the specimens had been captured with several different contact pressures from 0 MPa up to 30 MPa respectively to the different contact conditions in a deep drawing press. In the same context one-sided gap distances from 0.5 mm to 2 mm had been realized.

To verify the applicability of Newton's approach regarding the quenching experiments, the measured time temperature progression of the blanks during the experiment has been compared exemplarily with the analytically calculated cooling behavior using equation 1. Hereby the determined mean heat transfer coefficient between 800 °C and 400 °C had been applied for the calculation. Figure 2 illustrates the quality of the usability of equation 1 to describe the cooling behavior of the 22MnB5 specimens, with a neglectable divergence of both curves.

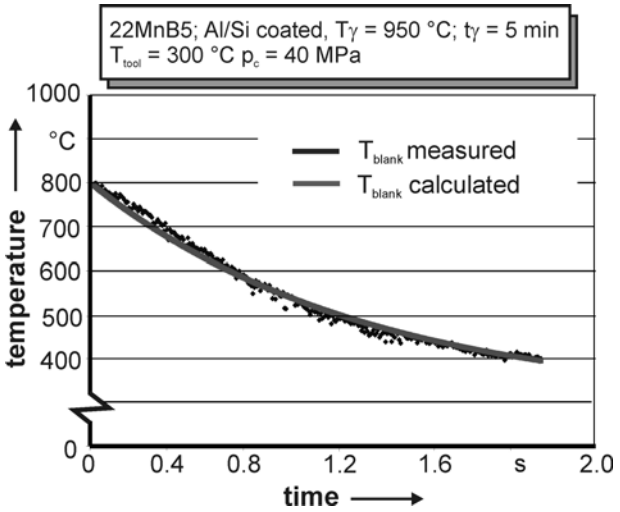

Figure 2: Comparison of measured and analytically calculated cooling behavior of AlSi coated specimens

5 THERMAL PROPERTIES REGARDING ELEVATED TOOL TEMPERATURES

The heat transfer coefficient α is responsible for the thermal behavior and the respective cooling of the blanks throughout the whole forming operation. As the mechanical properties of the base material 22MnB5 are strongly dependent on the temperature, this is one of the most important parameters that have to be taken into account regarding FE modeling of thermal assisted forming processes. The demand for a defined strength and ductility profile in the components achieved through partial press hardening requires the determination of heat transfer coefficients in dependency of different occurring tool temperatures. The heat transfer coefficients determined for varying tool temperatures of 20 °C, 100 °C and 300 °C respectively are displayed in Figure 3. The illustrated coefficients represent average values for a contact dependent cooling of sheet specimen within a temperature range between 800 °C and 400 °C. Hereby for all applied tool temperatures a noticeable contact pressure dependency can be detected. Moreover, for a tool temperature of 300 °C the highest average heat transfer coefficients of the three parameter variations could be obtained.

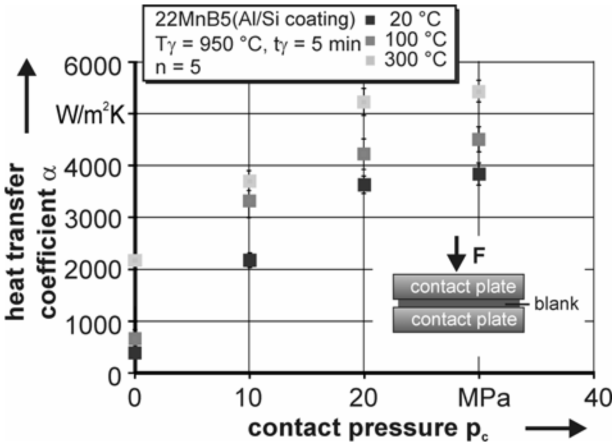

Figure 3: Heat transfer coefficient as a function of the contact pressure for different tool temperatures

Regarding the divergences between the values for the three temperatures, two main aspects have to be taken into consideration, namely the thermodynamic and the microstructural ascendancies. The higher the temperature difference between the two surfaces is set, the larger the driving force regarding the heat exchange between two contact partners. Another aspect is the smoothening of both the specimen's and the tool's surface and therefore the increase of the real contact area which leads in general to a raised heat transfer [6]. This is the main point, also in respect of the cooling rates. In Figure 4 it is obvious that the respective measured cooling rates are higher for specimens quenched at lower tool temperatures and therefore the temperature difference had been higher. But on the other hand the analytical impact of the tool temperature on the determination of the heat transfer coefficient is less significant than the gradient of the cooling rate.

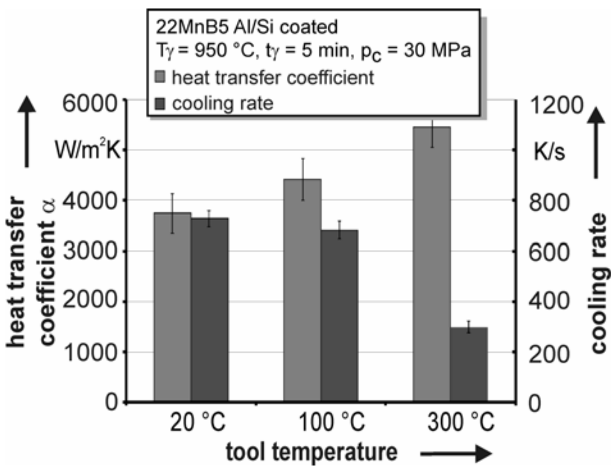

Figure 4: Heat transfer coefficient and cooling rate for different tool temperatures

So the divergences between the cooling rates and the heat transfer coefficients have to be induced by the impact of the real contact surface. This shows that the real contact surface comes closer to the geometric contact surface at elevated temperature unlike at lower temperature and therefore a correcting factor has to be implemented when calculating the heat transfer coefficient by using the assumption of the geometric surface. The contact surface used in Newton's cooling law for the determination of the heat transfer coefficient α is obviously a function in dependency of the contact pressure and the tool temperature. Regarding this fact, the equalization of the experimentally determined cooling rates of the specimens with an FE model is inevitable and is part of current investigations.
The aspects mentioned above lead to the values shown for the commonly used uncoated, but polished and hardened tool steel 1.2379. Regarding the different contact conditions occurring during deep drawing processes, also different gap distances have to be mentioned. Therefore, using templates, enabling the machine to be adjusted at distances of 0.5 mm up to 2 mm, which represent typical gap measurements e.g. appearing in cup deep drawing tests. Figure 5 represents the determined α-values using Newton's cooling law, taking several different gap distances in dependency of the tool temperature into account

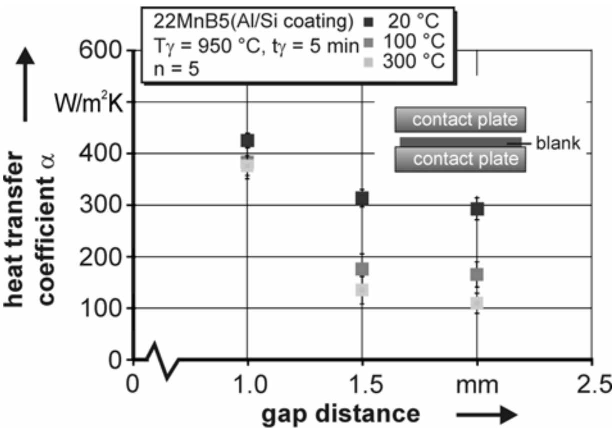

Figure 5: *Heat transfer coefficients for different one-sided gap distances in dependency of the tool temperature*

Hereby obviously the heat exchange between hot blank and tool surface decreases with progressive tool temperature behavior. This can be explained by Newton's cooling law, as the temperature difference between hot blank and tool is decreasing and so is the driving force for the heat exchange. The impact of surface smoothening at elevated tool temperatures is hereby not recognizable, or at least the temperature difference seems to be the more significant influencing factor.

6 CONCLUSIONS

The focus of the investigations presented in this paper had been on the characterization of the cooling behavior of boron manganese steel blanks with respect to partial press hardening. To take this into account quenching test with a heatable quenching tool have been performed in dependency of the contact pressure and different occurring gap distances, following the time temperature profile of the hot stamping process. The subsequent calculation had been taking place using Newton's cooling law. In this context a significant dependency on the tool temperature had been observed, whereby a rising heat transfer at higher tool temperature had been recorded for pressure capture, but decreasing heat transfer coefficients for one-sided gap distances. This clearly shows the obvious impact of the real contact surface at pressure loads, in contrast to the thermal behaviour at distant tool position. Further research work on the surface roughness and topography is essential to explain this behavior which is also focus of current investigations.

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