Current and Future Trends in the field of Hot Stamping of Car Body Parts
Ralf Kolleck, Robert Veit, Graz University of Technology, Institute Tools & Forming, Inffeldgasse 11, 8010 Graz, Austria

Summary
Hot stamping of boron alloyed steels has achieved high significance for the production of high strength automotive body parts. The number of production facilities is increasing where the conventional process with the boron alloyed steel 22MnB5 in its coated or uncoated variant is used. With hot stamping it was the first time that a heat treatment process entered the press shop and thus an adjustment of the part properties got feasible. As the equipment now is available, there are still many possibilities to improve the process efficiency or to reach an improved part performance.

This paper will give an overview on the latest developments in the field of hot stamping beginning from heating to tool technologies. Special attention will be paid to alternative sheet materials which lead to special part properties, giving hot stamping new fields of application in the car body.

Key words: Hot Stamping, Materials, Coatings, Tool Technologies, Trimming

Introduction
Hot Stamping of boron alloyed steels gained more and more importance over the last years. This is reflected in the increasing number of hot stamped parts in modern car bodies and consequently in an increasing number of corresponding production lines. The industrial application of this technology in car body production just started in the early nineties. In 2009 already more than 110 hot stamping production lines were in service and still their number is increasing [1].

For hot stamping quenchenable boron-manganese alloyed steels are used which allow a quite moderate critical cooling rate of only 27 K/s which is necessary for the transformation of austenite into martensite. In principle there are two different process variants of hot stamping: direct and indirect hot stamping. In the direct process a plain blank is heated up to austenitization temperature and formed and quenched in the forming tool. The indirect process works with a preformed component which is heated up to austenitization temperature and calibrated and quenched in a water cooled tool afterwards [2]. An alternative process sequence of the indirect hot stamping process was developed by voestalpine [3]. Here the component is not only cold formed to its final geometry, but also all trimmings and holes are brought in before austenitization and quenching takes place. As this process variant works with zink-coated sheet materials, the produced components offer a good corrosion resistance. In all cases the produced components fulfilling the requirements of crash behaviour, characterised by a high strength of about 1500 MPa and a residual elongation of about 5%.

Looking at the process chain of hot stamping (figure 1) there are four major fields of research: Materials and coating, heating technologies, new tool-concepts, tool materials and process routes and following operations.
Materials and Coatings

Despite of the industrial application of hot stamping for almost 20 years, there is still only one base material that is used for this application, the boron alloyed steel 22MnB5 with the material number 1.5528. For the quenched condition the indications of the different steel suppliers vary only marginally showing a yield strength $R_e$ of 1100 MPa, a tensile strength $R_m$ of 1500-1650 MPa and an elongation at fracture $A_{80}$ of 5-6 %. Lately ThyssenKrupp Steel Europe presented a new material concept for hot stamping: MBW 1900. With this steel concept a yield strength of 1200 MPa and a tensile strength of more than 1900 MPa are reached [4]. This could lead to a further weight reduction of high strength components. But in general the relatively low elongation at fracture limits the application of hot stamping to parts which are not deformed during crash. These are e.g. parts of the passenger’s compartment like a-pillars, b-pillars, the tunnel or bumpers. It can be assumed that the light weight potential of boron alloyed steels is almost used up. As the production facilities now are available and heat as a process parameter is already introduced in the press shop, new materials have to get into the focus of future investigations.

One approach is the use of stainless steel, which offers the advantage of good corrosion resistance of the formed parts. As there are different steel concepts, there is a wide range of mechanical properties that can be achieved which increases the field of application in the car body. Also the critical cooling rate is much lower than with 22MnB5 and even cooling on air can be considered. [5] Corrosion resistance and the avoidance of scale formation during the heating of the material are the main drivers for the development of new coatings for hot stamping. Currently there are only three industrial relevant coating systems available: Zinc, Aluminum/Silicon and x-tec. Zinc coatings can only be used for the indirect hot stamping process because at the austenitization temperature a further forming step would lead to zinc adsorption at the grain boundaries. This would cause delayed cracks in the component [6]. X-tec is a paint system based on nanotechnology which avoids scale formation during heating but offers only a
limited corrosion resistance for the formed component. The coating can be used for both process variants of hot stamping [7].

Because of the minimum number of process steps the direct hot stamping process is the one which is actually preferred in automobile industry. Here mostly Al/Si-coated blanks are used. The coating consists typically of approx. 87 wt.% aluminum, 10 wt.% silicon and, 3 wt.% iron in average. The melting temperature of the coating lies at 580 - 600 °C. During the heating of the blanks, Fe diffuses into the coating which leads to an increased melting temperature [8, 9]. That leads to the problem, that in conventional roller hearth furnaces the liquid coating will stick on or perhaps even diffuse into the ceramic rollers. This requires a high amount of maintenance, because the rollers in the respective areas of the furnace must regularly be replaced.

To avoid the liquid phase of the coating a new coating system (GammaProtect) has been introduced by ThyssenKrupp Steel Europe. It consists basically of electrolytically deposited zinc with a small content of nickel. As its melting temperature is at 881 °C, scale formation and the contamination of the rollers in the furnace can be avoided. [10] But it has yet to be shown that this product is capable of fulfilling the requirements of the automotive industry.

For any new development the requirements are clear. The OEMs will not accept any reduction of the weldability or paintability of the material. Also the corrosion resistance will have to be comparable or even be better than with existing coatings. Costs still have to be reduced and improvements have to be made concerning a reduction of heating times.

Heating Technologies

Conventionally continuous furnaces like roller hearth or walking beam furnaces are used for hot stamping. The blank is heated by radiation and convective flow of heat. Depending on the country of use these furnaces are heated even with gas or electricity. The heating rate of the blanks is controlled by the speed of the rollers or the walking beams on the one hand and by the temperatures in different consecutive chambers on the other. The sheet thickness as well as the coating and therefore the emission coefficient have a great impact on the heating behaviour and the effective sheet temperature.

With a typical length of more than 40 m, conventional furnaces require very large spaces and consume a lot of energy. The energy efficiency of such a furnace reaches only 55% with an optimum load of the furnace [11]. As great efforts are being undertaken to reduce the cost of components by reducing the cycle time, higher trough-put-rates are necessary which would lead to even longer furnaces. To avoid this, different approaches are presented.

The concept of a two-floor roller hearth furnace, presented by Schwartz, offers the advantage of a highly reduced installation length. Furthermore the energy efficiency can be improved when part carriers are used in the indirect hot stamping process [12]. But apart from that, the heating technology is state of the art with the known problems of high wear of the rollers and little flexibility when the furnace has to be switched off.

The contamination of the rollers by liquid Al/Si can be avoided with a set of chamber furnaces because there is no relative movement of the sheet during heating. These furnaces are grouped on top of each other and side by side [12]. The cycle time depends on the maximum sheet thickness, the coating and the number of furnace chambers. The installation requires less space compared to
continuous furnaces, but it can be assumed, that the energy consumption is higher. There might be another problem after the heating of the blank. As the distance between forming tool and the particular furnace chamber is different, the heat loss during the manipulation of the blank may differ. This could lead to an unstable process or non reproducible part properties.

In conduction heating, the heated component is connected in series with a power source. Due to the electric resistance of the component the heat is generated proportional to the loss of power. The efficiency factor of conduction heating is directly depending on the geometry of the blank. Due to the electrical serial connection of blank and feed line the efficiency factor is defined by the ratio of the two resistances. This is the reason why conduction heating is mainly used for components with a favourable length/diameter ratio, such as pipes, rods, wires and bands. Also a homogenous heating of shaped blanks is quite difficult due to the changing resistance in relation to the cross section [13]. So an application of this technology in hot stamping seems not feasible.

Induction heating devices for the heating of the blanks offer the potential of increased energy efficiency, reduced cost and reduced floor space. An induction heating device consists of two components, a high-frequency generator and an induction coil, the so-called inductor. When the sheet enters the inductor, a current is induced in it. This eddy current is short-circuited and results in heating, depending on the operating frequency, the electrical conductivity and the permeability of the material. Induction heating offers the highest surface power density, so very high heating rates can be reached [14]. It was proved, that with uncoated material the same part properties can be reached than with conventional heating [15]. With a new combined furnace concept also Al/Si-coated sheets can be heated and heating time can be saved.

**Tool and Process Technologies**

To reach the critical minimum cooling rate of 27 K/s is not a challenge in the hot stamping process. But the minimum cooling time till the part can be released of the tool defines the bigger part of the cycle time. Thus, a lot of research work is done to improve the cooling performance of the tool. New tool materials with increased thermal conductivity are one approach [16]. But in a first step it is important to analyse or rather forecast the cooling performance of the tool, to be able to design an optimized cooling system. Here the combination of FEM and CFD-Simulation will gain importance in the coming years [17].

Currently, cooling of tools is mainly performed by segmented tools with drilled cooling bores, or by tools with milled cooling channels in a surface shell. Another alternative method is to cast-in cooling geometries [18]. The manufacturing of near-surface cooling channels combines a cutting and a laser cladding process. The cooling channels are milled into the active surface of a tool, covered by custom-fit inlays from mild steel and coated with a laser cladding layer in order to seal the inlay and to produce a leak-proof connection to the material of the tool (see figure 2).

The feasibility of the new manufacturing method of near-surface cooling channels for tempered tools was shown by the help of a real forming tool. The comparison between the simulation and the real process still shows deviations in the estimated temperature. Nevertheless the qualitative temperature distribution is predicted quite well (figure 3).
The simulation of the cooling performance of hot stamping tools may also be of great assistance when it comes to the utilisation of alternative process routes. Normally a full martensitic transformation is desired. But alternative routes through the time-temperature-transformation diagram lead to different microstructures. When a part is cooled down rapidly from austenitization temperature and held just above martensite start temperature bainite is produced. Bainite shows a higher ductility which could be favourable for parts that have to absorb energy during crash [19]. But to be able to use this potential a good knowledge about the cooling performance of the tool and high process stability is necessary.

The adjustment of the microstructure can also be applied locally. Therefore different process variants are available (figure 4). One approach is to heat the blank completely and to keep the areas which have to be quenched in a secondary
furnace on austenitization temperature. The future soft zones are exposed to air or cooled by a controlled stream of air where the cooling rate is below 27 K/s. A current example for the use of this technology offers the B-pillar of the VW Tiguan [20].

A more energy efficient way to produce parts with locally adjusted strength is the application of induction heating. As the energy input can be controlled easily, the temperature can be defined precisely in longitudinal direction of the part [21].

One tool technology to produce areas of reduced strength is the use of thermally insulation tool inserts. Here the feasibility was proved with different materials [21, 22]. As a reduced cooling rate increases the cycle time, this approach should only be applied to small areas of the part. Thus the trimming lines could be softened to allow the hard cutting of the blank.

Following Operations
Trimming of hot stamped parts is still a challenge in the process chain. Due to the high strength of the produced parts tool wear is really high. Thus in the industrial application laser cutting is the most common process. The cycle time of laser cutting could be reduced by more than 60% in the last five years [23]. This increases the need for an optimization of the trimming process. First investigations of the trimming process by So, Hofmann and Golle give an insight into the basic mechanisms. Also trimming of the part at elevated temperature inside of the forming tool was investigated [24]. From the economical point of view, this seems to be the most promising approach.

Conclusion
Hot stamping already is a very important technology for the production of body parts. Looking at the manifold fields of current research works it can be assumed, that this technology will persist and further advances can be expected. As it is the first time, that heat is used in sheet metal forming, it’s a question of time that this new process parameter is transferred to other applications.
References


