IMPROVING THE QUALITY OF HOT STAMPING PARTS WITH INNOVATIVE PRESS TECHNOLOGY AND INLINE PROCESS CONTROL

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Abstract. The increasing number of hot stamped parts in the automotive industry is challenging different process areas. This paper presents a method how to improve the production rates over the whole life cycle of a hot forming part. In the core element of a hot forming line, the hydraulic press, mainly two processing steps are performed. Forming and quenching of the sheet metal part. In addition to the forming operation, it is inevitable to optimize the quenching condition in the bottom dead center in order to reach a fully martensitic structure and tight geometrical tolerances of the part. Deviations in the blank thickness, tool wear, polishing of classical tools impair the quenching condition and therefore the part quality over the time. A new press and tool design has been developed to counter this effect by providing homogenous contact pressure over the whole die. Especially with a multi cavity tool, the new method is advantageous. Test series have shown that the new tool and press concept can produce parts with a blank thickness of 1.0 mm within 8.0 s cycle time. The so called PCH flex principle makes it possible to produce such high output rates under reliable conditions.

1. Introduction
Since the first integration of hot stamping components in car bodies in the early eighties many further developments have turned this manufacturing process into a key technology in the automotive industry. Current car bodies have a share of hot stamped parts of nearly 40% in mass of BIW [1]. Advantages regarding the light weight potential of the material and the increasing safety demands are still pushing this production technology for ultimate high strength steel (UHSS) parts with an ultimate tensile strength up to 1900 MPa. Since the integration of such parts in the compact car and transportation vehicle segment, the worldwide production capacities will have to increase even further.

As a world leading press manufacturer, Schuler has been part of this development from the very beginning. As system integrator Schuler assumes responsibility for turnkey hot forming lines including automation, heating technology, press and quality assurance issues. In 2016 a new press generation has been introduced to the market which offers higher flexibility, productivity and energy efficiency. For higher rates of part production it is necessary to reduce the cycle time. To reach this goal, an optimum cooling condition in the technical system part, die and press is most important. For this reason a new flexible cushion technology called PCH flex has been developed to improve the contact pressure which should be high and constant over a multiple-out die.
2. State of the art

In direct hot forming, an austenitic blank with a temperature of approximately 930 °C is transferred from the furnace into a forming tool within a few seconds. Just before forming it reaches a typical temperature between 650 and 850 °C. After forming it is cooled down under high contact pressure in a die at a minimum cooling rate of 28 K/s [2]. This guarantees a fully martensitic structure with optimum strength of the material which is well described in literature [3,4]. In reality however much higher cooling rates of more than 100 K/s can be achieved [5] which is essential for higher production rates. It is shown that the cooling performance of a hot stamping part is correlating with the overall thermal resistance between the sheet metal and the cooling ducts. The thermal resistance is mainly dependent on the following factors:

- Geometrical factors:
  - Thickness of sheet metal
  - Distance from die surface to cooling duct
  - Density and distance between cooling ducts
- Physical material properties
  - Thermal conductivity of sheet and die material
  - Heat capacity
- Interfacial properties
  - Contact pressure
  - Temperature difference
  - Roughness
  - Flow properties of cooling medium

There is a technical limitation to optimize geometrical and physical properties, whereas further potential of improvement of the interfacial properties is available. Weiss et al shows [6] that the heat transfer coefficient (HTC) between blank and die has a share of about 40% regarding the total thermal resistance a significant adjusting screw to shorten the quenching time. The dependency of the HTC was investigated through different testing procedures and institutions [7]. It is mainly affected by the temperature difference [8] and the contact pressure between the two contacting bodies [9]. The increase of the HTC with rising contact pressure as shown in figure 1 can be explained with surface smoothing and the resulting higher surface contact areas. Deviations between different evaluations can be explained by different test methods, temperatures and tested die materials. Nevertheless it can be clearly seen that most of the HTC curves have a degressive course with an optimum between 10 and 20 MPa to combine sufficient heat transfer and technical feasibility.

![Figure 1. Determined HTC values as function of the contact pressure [4,9,10]](image)

Technical uncertainties such as deviations in the blank thicknesses, bending of the press table, die and tool wear lead to inhomogeneous contact pressures, especially in multi cavity dies. In the worst
case scenario, small air gaps between blank and die surface result in a low thermal flow and HTCs found to be lower than 500 W/m²K [11]. This potential of improvement has led to a new reliable press and forming tool concept developed by Schuler.

3. New press concept
The third generation of hot stamping presses is excelling in terms of energy efficiency and innovative technology to suit the requirements of a state-of-the-art stamping process. In this respect, Schuler has focused the engineering work on the reduction of cycle times, the increase of output figures, the product flexibility and the consistency of product quality. Figure 2 shows an example of a new generation press.

The most suitable approach to solve the problems described above is the use of a flexible hydraulic bed cushion called PCH flex in the hot stamping press. The high transition of heat from the part to the stamping die which is distributed uniformly to all areas leads to the quick cooling of the part and reduces the formation of hot spots. At the same time, inaccuracies in the blank, die and die cavity as well as the elastic deflection of the press table are eliminated by the hydraulic system.

As a consequence, the tryout times on the hot stamping press are shorter, the changeover of dies from one production line to another is faster, and the manual adjustment of the die cavities, the so-called “shimming” is eliminated. In addition, the all over homogeneous contact between blank and die leads to a reduction of the cycle time and enhances the availability of the entire hot stamping line.

The main idea behind the new technology is to realize the part quenching in dead bottom center between floating mounted die cavities with hydraulic counter pressure. This counter pressure is applied flexible on every die cavity of a multiple-out die. To guarantee a homogenous force distribution a PCH pin matrix with a centre-to-centre distance of 150 mm is realized. The PCH flex cushion consists of 105 hydraulic cylinders individually activated and controlled. The maximum stroke and force of each cylinder is 10 mm and 315 kN. Since the bed cushion force is not introduced through a cushion plate but directly into a vertical guided die insert with pins, a very high uniform pressure is applied to all horizontal surface areas of the part. Dependent on the die layout, every cavity is supported by a pattern of several activated PCH cylinders. The principle is shown in figure 3. Every die cavity (up to four) can be equipped with different hydraulic functions (bolster, blank holder and ejector) and is connected to the PCH cushion technology. With this principle deviations in blank thickness, tool wear and bending of the press table and die can be easily compensated and reduced.
Height adjustments between the single cavities and compensation of dimensional bending deviations are not necessary anymore because this is done automatically with the PCH flex system. Even small changes of tool wear can be adjusted. Depending on the part size and geometry, the counter pressure of the cushion can be adjusted to reach an optimum cooling time and geometrical accuracy of the part. Hot spot formation can be reduced significantly by this technology. It is well known that a homogenous contact pressure over all cavities is cooling the hot stamping parts to a more homogenous temperature distribution. Smaller deviations in temperatures lead to less thermal distortion after unloading the part from the die which means significant higher part quality. Nevertheless gaps in the vertical area of the parts have to be shimmed during try out.

4. Test principle
To test the PCH principle a three-out test die with two rocker panels and a b-pillar is built as shown in figure 4. The rocker panels have a nominal sheet thickness of 1.0 mm, the b-pillar of 1.5 mm. To test the limits of the motion control only the 1.0 mm parts are investigated with the parameters shown in table 1. Objective of the test series is to look at the development of the maximum ejection temperature of the parts in quasi stationary condition. This temperature should be lower than 230 °C (martensite finish temperature) to guarantee the demanded metallurgical properties and low part distortion because of high temperature gradients within the part.

| Part                           | Rocker panel |
|-------------------------------|--------------|
| Sheet thickness               | 1.0 mm       |
| Heating time                  | 240 s        |
| Heating temperature           | 930 °C       |
| Cycle time (part to part)     | 8 s          |
| Quenching time (dead bottom center) | 2 s     |
| Maximum press force           | 1200 kN      |
| (for all three cavities)       |              |
| Minimum calculated contact pressure | 10 MPa |
| Number of cycles              | 12           |

Figure 3. PCHflex cushion principle on a four-out die
5. Results
With a kinematic optimization of furnace, transfer and press automation a cycle time of 8.0 s can be reached with a quenching time of 2.0 s. That means that with this configuration the output rate is 7.5 parts per minute. Figure 5 shows the temperature development of the right and left rocker panel within 12 strokes. The measurements are made with a FLIR infrared camera. The emission coefficient is calibrated with comparing measurements and set to 0.65. For this thermocouples were laser welded onto the part surface to avoid a change of surface condition. The calibration measurement was done with three repetitions. It has to be considered that within the observed temperature field the emission coefficient shows a slight temperature dependency which can be neglected for this test series. It can be seen that the quasi stationary condition is reached after approximately eight parts. The pictures show homogenously cooled parts with higher temperature in vertical areas.

![Figure 4. Test die – three out – rocker panel left/right and b-pillar](image)

![Figure 5. Temperature development of right / left part immediately after part ejection](image)
Figure 6 Measured ejection temperature of right / left part of 12 cycles

All maximum temperature values are lower than 230 °C which guarantees full martensitic structure. The mean part temperatures are in the range of 125 to 145 °C which is presented in figure 6. Mechanical testing of the parts regarding hardness and ultimate tensile strength show values within the material specifications.

6. Conclusion and Outlook
In the future, the importance of hot stamping systems with a fast, reliable and stable process and an optimized interchange between hot stamping equipment and quality assurance will increase and become the most important competition advantage for part manufacturers. Schuler presents with its new PCH flex technology a system which meets these requirements by achieving a production cycle time of 8.0 s of hot stamping parts with a thickness of 1.0 mm. It is demonstrated that the required quality criteria of the parts can be reached under such extreme conditions. Nevertheless further development will be done at Schuler to improve the hot stamping process in the future to guarantee a high quality part output in the most productive way.

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