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Hot Stamping With Modified Process Route for the Production of Thick Sheets With Optimized Fatigue Strength Properties

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Abstract

Hot-stamping is one of the most important processes for manufacturing ultra-high-strength components. Particularly in automotive chassis construction, hot-stamped components are very popular for meeting lightweight requirements because of to their good strength-to-weight ratio. Due to legal regulations, lightweight efforts are also increasing in the area of heavy-duty vehicles, opening up potential for the use of hot-stamped components as well. Up to now, fine-grain structural steels with sheet thicknesses of up to 9.0 mm were the main materials used. The substitution of these sheets with thinner, hot-stamped components offers great lightweight potential and is therefore being researched. In order for the hot-stamped components to be used in this area, they must meet special requirements. As a result of the long service life, particular focus is therefore placed on fatigue strength. For this reason, the conventional process route of hot-stamping was optimized in this work so that hot-stamped thick sheets of the manganese-boron-steel 22MnB5 with improved fatigue strength properties can be produced economically. Therefore, conventional furnace heating was substituted by resistance heating. In addition, the influence of sandblasting as a post-treatment was investigated.

1 Introduction

In the context of increasing environmental regulations and stricter safety requirements [1], the use of ultra-high-strength sheet metal materials has become established in automotive body construction in recent years. These materials enable the use of even thinner sheet metal while maintaining or even increasing its strength [2]. A key technology for the production of ultra-high-strength components is hot stamping, which has established itself industrially in recent decades and is used in particular for the production of structural parts with extremely high strength properties [3]. By heat treating the material, the process enables the production of components with tensile strengths of up to 1500 MPa, which are used in particular for crash-relevant applications in the car body structure. A major advantage of the process is that the heat treatment can be combined with the forming of the sheet metal using suitable process routes [4].

The high forming accuracy resulting from the process and the absence of springback effects due to residual stresses enable the production of near-net-shape components that do not require almost any post-machining. At the same time, however, the elongation at break of the material drops from over 20 % in the as-delivered state to around 6 % in the final hardened state [5]. In the past, the manganese-boron steel 22MnB5 has become the most popular hot stamping material due to its property profile [6]. The described advantages of the process also qualify hot stamping for other applications. A possible area of application for hot-stamped components is, for example, chassis for heavy-duty vehicles. In this special application, materials and structures must be used that can absorb many times the forces and payloads of passenger cars. At present, hot stamping is not widely used in this area, as lightweight construction has not played such an important role for a long time. However, political efforts to reduce emissions and increasing safety requirements will make the use of ultra-high-strength components unavoidable in the future [7]. For this reason, hot stamping could also play a major role in manufacturing in the future. In order for hot stamping to become established on an industrial scale in the heavy-duty vehicle sector, certain requirements must be met. The structures have to achieve significantly longer lifetimes in terms of mileage. To achieve this, higher sheet thicknesses must be used compared to normal passenger car structures. Fatigue behavior is also of decisive importance [8]. In this respect, fatigue strength is particularly important. For this reason, various studies on the fatigue strength of 22MnB5 have already been published in recent years. The majority of the studies focus on the influence of defects caused by the stamping of blanks [9, 10] and the application of an Al-Si coating [11, 12]. A general finding is that 22MnB5 is very sensitive to these defects [10]. In addition, Picas et al. investigated the influence of microstructure on fatigue strength. They determined that the sensitivity to pre-existing defects decreases with a softer microstructure, as does the fatigue strength [9]. For hot forming of thick sheets, studies were carried out by Sunderkötter et al. [8] and Pujante et al. [13]. In the former work, fatigue tests were carried out on 6 mm thick homogeneous hot-formed specimens and it was found that an additional tempering step can have a positive effect on fatigue strength. Further studies focused on decarburization effects on high-cycle fatigue of uncoated press hardened steels. Baser et al. found that the presence of the decarburized layer has a significantly negative influence on the fatigue properties of the press hardened 22MnB5 steel [14]. The reasons for this are the reduced hardness and the formation of tensile residual stresses that have a negative impact on the fatigue behavior [15].

The area of heavy-duty vehicle structures offers further potential for research, as the focus here is on the hot stamping of thick sheet metal. The production of hot stamped thick sheets with optimized fatigue properties has been insufficiently investigated so far. The aim of the investigations presented here is to investigate the fatigue behavior of thick sheet metal that has been hot stamped using a conventional process route. By specifically adapting the process route, the component properties are also to be optimized with regard to their fatigue strength.

2 Materials and Methods

2.1 Materials

In this study the heat treatable steel 22MnB5 with a sheet thickness of 6.0 mm was used. The material was provided without coating. The chemical composition of the material, which has been analyzed by spark spectroscopy, is presented in Table 1. The main element of this steel is Fe. For the tests, sheets measuring 295 x 155 mm were cut out of a 22MnB5 sheet using a waterjet cutting machine. These were then subjected to heat treatment and hardened in a plate tool.

Table 1: *Chemical composition (mass contents in %) of investigated Fe-based 22MnB5 sheet*

Material	C	Si	Mn	B	Al	Ti	Cr	Mo
22 MnB5	0.22	0.21	1.16	0.004	0.036	0.04	0.34	0.071

2.2 Process Route for Hot Stamping of Thick Sheet Metal

As part of the studies presented here, components made of the material described in chapter 2.1 were hot stamped in various configurations and then analyzed in terms of fatigue strength. Initially, reference components were manufactured using a conventional process route, as is currently used in industry. The conventional process route is shown in gray in Figure 1. According to this route, the sheet metal is first heated in a chamber furnace after the blank is pre-cut. The metal sheet is heated to the required austenitizing temperature (approx. 950 °C for 22MnB5). The hot sheet is then transferred to the plate tool of a forming press, where the actual hot stamping process takes place. In order to produce a martensitic microstructure, which is essential for a successful hot stamping process, a cooling rate above the critical cooling rate of 27 K/s is required. This is achieved by specially cooled tool surfaces in combination with a high contact pressure of approx. 30 MPa. After cooling, the component can be removed and is ready for assembly.

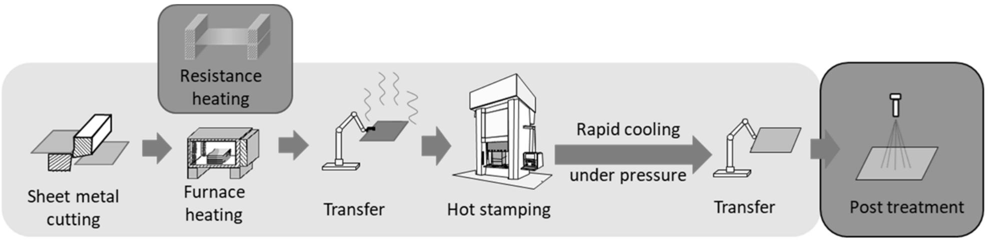

Figure 1: *Schematic process route for hot stamping (light grey: conventional route, dark grey: adapted process route)*

With the aim of optimizing the components in terms of their fatigue strength, the process route was optimized as part of the investigations (see Figure 1, green). Instead of the chamber furnace described above, a resistance heating system was used. In contrast to indirect heating in the furnace, this offers the possibility of direct heating of the component. As a result, the component can be heated significantly faster. Since the material is uncoated and no time for diffusion of the coating must be considered, the heating time can be reduced from 330 s (oven) to approx. 27 s (resistance heating). Resistance heating is therefore around 12 times faster for this particular component. Furthermore, the process route was extended to include post-treatment in the form of blast cleaning after hot stamping. Here, the components were treated in a cleaning blasting chamber with corundum F30 as the blasting material. Components were manufactured using the new process route as part of the investigations and compared with the reference components from the conventional process route.

2.3 Testing of Fatigue Strength Properties

For comparing the manufactured components fatigue strength was defined as the decisive criterion. This was tested on a 4-point bending device (see Figure 2, left). This device is a resonance-testing device that applies a constant bending moment on the material specimen (see Figure 2, right). The test frequency is approx. 20 Hz.

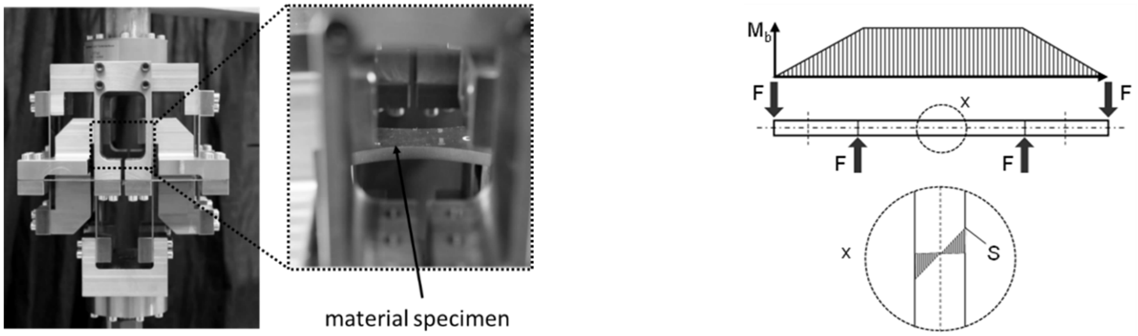

Figure 2: *4-Point-bending test device with material specimen (left) and bending moment along specimen length (right)*

The tests were carried out in the fatigue strength range using the pearl string method in accordance with DIN 50100:2016. The maximum number of cycles was 2 million and the bending stress was applied to the material specimen with a stress-ratio of R = -1. The samples required for the tests were cut by water jet cutting after hot stamping (see Figure 3). In order to avoid influencing the cut edges with regard to their fatigue strength and to establish comparability of the specimens, the waterjet cutting parameters were kept constant and the cut edges were not machined afterwards.

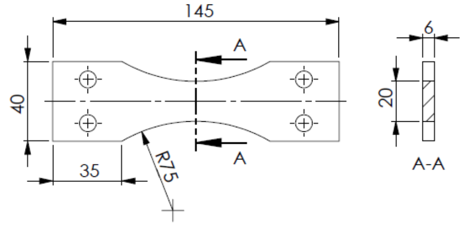

Figure 3: *Shape of specimen for the fatigue tests*

3 Experimental Results

With the test device described in chapter 2.3, fatigue strength tests were carried out and S-N curves were recorded. The following section shows the results for the specimens produced according to different parameter configurations and compares them with each other. The influence of resistance heating as an alternative heating method and the influence of post-treatment by cleaning blasting with corundum F30 were investigated.

3.1 Influence of the Heating Strategy on the Fatigue Strength of Hot-Stamped Thick Sheets

This chapter describes the influence of the heating strategy. Figure 4 shows the S-N curves of the component samples that were produced using different heating strategies. The reference component, which was produced according to the conventional process route with heating in a chamber furnace (V01), achieves a steep slope of the high cycle fatigue line of k = 2.9 and a long-life fatigue strength of $S_{aL} = 295$ MPa. The components produced by resistance heating (V02) achieve a less steep slope of k = 4.1 and a long-life fatigue strength of $S_{aL} = 369$ MPa. The fatigue strength of the resistance-heated samples is therefore approx. 25 % higher than that of the furnace-heated samples. With both heating strategies, numerous crack initiations form due to the fatigue test, which can be seen in Figure 4, above. However, the number of crack initiations appears to be lower for resistance-heated sheets. This could be due to less scale formation during the heating process.

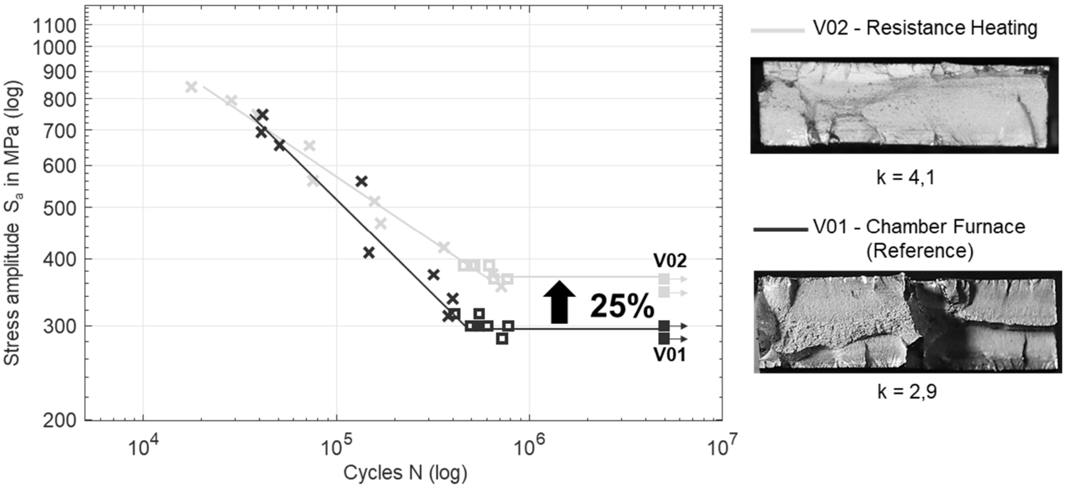

Figure 4: S-N curves of the different heating methods (left) and fracture surfaces of the material specimens (right): x = failure in finite life fatigue, square = failure in high cycle fatigue, square with arrow: runout specimen

Another reason for the reduced tensile strength of the furnace-heated samples is provided by the micrographs (see Figure 5). The lighter appearance of the microstructure in the edge area of the furnace-heated specimen (V01) indicates the occurrence of surface decarburization. This occurs due to the long heating time in the furnace and, according to [15], favors the formation of residual tensile stresses. Residual tensile stresses promote the formation of cracks under bending stresses and thus reduce the fatigue strength.

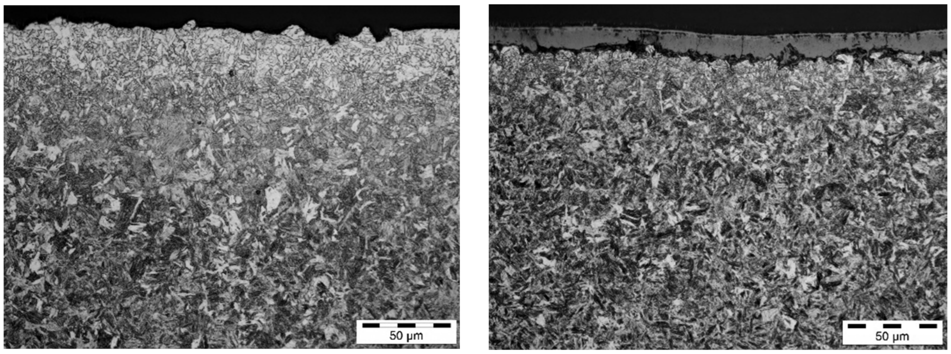

Figure 5: Metallographic micrograph of V01 (left) and V02 (right)

3.2 Influence of Post-Treatment on the Fatigue Strength of Hot Stamped Thick Sheets

In this chapter, the influence of post-treatment on the fatigue strength is shown. Figure 6 again shows two S-N curves of samples that were produced using the different heating strategies described. This time, however, in both cases, the samples were subjected to post-treatment by cleaning blasting with corundum F30 after hot stamping. The figure shows that in this case, the resistance-heated samples (V04) achieve better fatigue strengths than the furnace-heated samples (V03) as well (547 MPa compared to 440 MPa). This corresponds to an improvement of approx. 24% and is in line with the results from chapter 3.1.

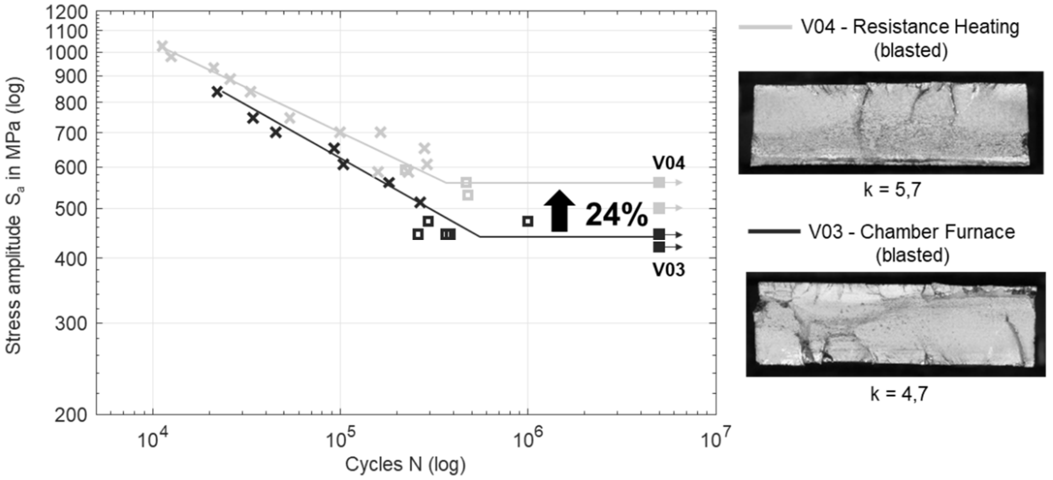

***Figure 6:** S-N curves of the blasted and non-blasted material specimens (left) and fracture surfaces of the material specimens (right): x = failure in finite life fatigue, square = failure in high cycle fatigue, square with arrow: runout specimen*

The comparison of the absolute values also shows that the additional cleaning blasting significantly increases the long-life fatigue strength for both heating strategies. Regardless of the heating strategy, it is possible to achieve approx. 50% higher fatigue strength. An examination of the fracture surfaces reveals that significantly fewer cracks occur on the surface of the blasted material samples than on the unblasted samples, see Figure 6 (right). This is presumably due to the development of residual stresses on the surface as a result of the post-treatment, which in this case have a positive effect on the fatigue strength.

4 Summary and Outlook

As part of the investigations presented here, the conventional process route for hot stamping, which is used in industry today, was optimized in order to produce thick sheet metal made of 22MnB5 with improved fatigue strength properties. By implementing resistance heating instead of furnace heating and a subsequent post-treatment by cleaning blasting, the fatigue strength of the sample components was significantly increased. The modified heating strategy results in an increase in fatigue strength of approx. 25%. Cleaning blasting even improves the fatigue strength by approx. 50% compared to the reference sample. In total, the combination of these two process steps can produce components with around 85% higher long-life fatigue strength compared to the conventional process route. These properties can be used in further research work to optimize structures in the field of heavy commercial vehicles in terms of lightweight construction. The generation of graded component properties, i.e. properties that vary over the cross-section, could also provide further potential for increasing fatigue strength.

In this regard, further tests with an intermediate cooling step are planned in order to obtain these graded properties in the FOSTA research project 22081N. Furthermore, microstructural analyses are planned in order to determine the composition of the microstructure via the sheet thickness. With regard to crack initiation, a softer surface in combination with a hard core could be a desirable combination.

Acknowledgements

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References

[1] Van Ratingen, et al.: The European new car assessment programme: a historical review. In: Chinese Journal of Traumatology, Volume 19 (2016), Issue 2 pp. 63–69.

[2] Taylor, T; Clough, A: Critical review of automotive hot-stamped sheet steel from an industrial perspective. In: Materials Science and Technology, Volume 34 (2018), Issue 7: Pearlitic Steel Wires, pp. 809-861.

[3] Lechler, J., Merklein, M.:. Hot stamping of ultra strength steels as a key technology for lightweight construction. In: Materials Science and Technology (MS&T) (2008), Pittsburgh, Pennsylvania, pp. 1698–1709.

[4] Karbasian, H.; Tekkaya, A.E.: A review on hot stamping. In: Journal of Materials Processing Technology, Volume 210 (2010), Issue 15, Pages 2103-2118.

[5] Behrens, B.-A. et al.: Partial resistance tempering of hot-stamped components made of 22MnB5 for subsequent bending. In: IOP Conference Series: Materials Science and Engineering, Volume 1284 (2023).

[6] Diekamp, et al.: Optimised press-hardening process using spray cooling - Process integrated heat treatment of 22MnB5 sheet metal. HTM Journal of Heat Treatment and Materials (2011), pp. 316-322.

[7] Behrens B.-A., et al.: Modified hot stamping process and fatigue behavior of thick 22MnB5 sheets. Proceedings of the 3rd international conference on hot sheet metal forming of high-performance steel (2022), pp. 419-426.

[8] Sunderkötter, C. et al.: Press hardening of truck chassis components, 5th International Conference on Steel in Cars and Trucks (2017).

[9] Picas, I. et al.: Effect of the cutting process in the mechanical and fatigue properties of press hardened 22MnB5 steel. Proceedings of the 3rd international conference on hot sheet metal forming of high-performance steel (2011), pp. 85-92.

[10] Lara, A.; Picas, I.; Casellas, D.: Effect of the cutting process on the fatigue performance of press hardened and high strength dual phase steels. In: Journal of Materials Processing Technology, Volume 213 (2013), Issue 11, pp. 1908-1919.

[11] Albracht, L., et. al.: Coating Materials Under Oxygen-Free Silane Atmosphere for Hot Stamping, In: Proceedings of the 11th Congress of the German Academic Association for Production Technology (WGP), Dresden, September 2021. Cham: Springer International Publishing, pp. 3–10.

[12] Pessard, E. et al.: The effect of quenching and defects size on the HCF behavior of Boron steel. In: International Journal of Fatigue, Volume 68 (2014), pp. 80-89.

[13] Pujante, J. et al.: Microstructural and Mechanical Study of Press Hardening of Thick Boron Steel Sheet. In: Proceedings of the International Deep Drawing Research Group IDDRG 2017, International Conference, 2017.

[14] Baser, T.A. et al.: Decarburization effects on high-cycle fatigue of uncoated press hardened steels. In: Materials Testing, Volume 65 (2023), Issue 9, pp. 1322-1335

[15] Gegner, J. et al.: Charakterisierung von Randentkohlungsvorgängen bei der Austenitisierung des Wälzla-gerstahls 100Cr6. Teil 1: Korrelation zwischen Randschichteigenschaften und Kohlenstoff-Tiefenverlauf; Materialwissenschaft und Werkstofftechnik, Ausgabe 34 (2003), pp. 701-710.

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