Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 81 (2014) 1725 – 1730
Procedia Engineering
www.elsevier.com/locate/procedia

11th International Conference on Technology of Plasticity, ICTP 2014, 19-24 October 2014, Nagoya Congress Center, Nagoya, Japan

Hot stamping of high strength steel with tailored properties by two methods

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Abstract

Hot stamped components with full martensite exhibit ultrahigh tensile strength and hardness, whereas the poor ductility restricts their application on certain components, such as B pillar, which needs multi strength in different regions. It is essential to partly achieve softer structure with high ductility, to enhance the crashworthiness and energy absorption of the whole component and thus improving the safety performance. This work described the hot stamping of high strength steel with tailored properties by two methods, namely applying different die temperatures and annealing processes. The hardness distribution, tensile strength and ductility in different regions of the hot stamped components were gained under the conditions of above two methods to realize the tailored properties. Regardless of the decrease of tensile strength, the total elongation of annealed zone can reaches 20.6% while the heating zone can only obtain its elongation of 10.8%. The results show that annealing hardened part to get tailored properties brings about better performance.

Selection and peer-review under responsibility of the Department of Materials Science and Engineering, Nagoya University

Keywords: High strength steel; Tailored properties; Annealing; Die partition

1. Introduction

Due to the demand for reduced vehicle weight, improved safety and crashworthiness qualities, increasing hot stamping parts are used for automobile structural components from ultra high strength steel[1]. The general process

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Selection and peer-review under responsibility of the Department of Materials Science and Engineering, Nagoya University
doi:10.1016/j.proeng.2014.10.221

of hot stamping technology is listed as follows: forming high performance sheets in high temperature (over 900 ˚C) and quenching in-die, thereby obtaining homogeneous martensite and high strength martensitic component.

The full martensitic parts are characteristic of high strength (1500 - 1700 MPa) and poor ductility generally less than 5%. Therefore, generally high strength steel hot stamped parts are not suitable for the energy absorbing parts of automobiles [2].Except for increasing structural strength of vehicle, the issue of matching mechanical properties of parts and body security has been of concern. However, with the more widespread application of high-strength steel, the compatibility of mechanical properties and safety performance of vehicle parts has been proposed that different mechanical properties are needed in different regions of the same parts, namely tailored properties. Generally speaking, there are five ways to achieve tailored properties: tailor welded blanks; poor slab; different initial temperature of the blank; die material of different thermal conductivity; different die temperature; different contact area and subsequent heat treatment (tempering and annealing). By means of die slotting locally, Mori, K [3] successfully made the high strength of the contact area with the die and the low strength of the regions without contact. With the employment of tailor welded blanks, Pan [4] obtained the automotive B-pillar which can meet the crashworthiness requirements of roof and side, with a reduced part mass by 27.4%. Casas [5] varied the heat transfer coefficient from 7 to 66 W/mK using special equipment, which has controlled the heat transfer of blank effectively.

The present paper applied two methods to get tailored properties, namely dividing die into two zones (die partition) and annealing hardened part. This paper extends and consolidates the work described in Wang [6] and Xu [7]. In the research of George [8], a laboratory-scale hot-formed B-pillar was produced using a segmented die with local heating and cooling zones such that the cooling rate of the blank was controlled locally during the hot forming process. Svec [9] performed the experiments with a plate tool which exhibits a heated and a cooled zone according to the tailored tempering process. Merklein [10] controlled the cooling rate of the austenitized blank by local heating of the tool and consequently adjusting microstructure evolution and resulting mechanical properties. Annealing the hardened part has been researched to obtain tailored properties [11-13].This study focused on the contrast of the two methods to fulfill tailored properties.

2. Experimental procedure

2.1. Material and parameters

In this paper, the studied high strength steel belongs to boron steel specialized for hot stamping process, named WHT1500HF (Wuhan Steel, China). The thickness is 1.5mm and the composition is given in Table 1. Fe makes up the balance and the composition is provided by the material supplier.

Table 1 Chemical composition of WHT1500HF

Chemical elements	C	Si	Mn	P	S	Cr	Ni	Mo	Ti	B
Content [%]	0.20	0.85	1.64	0.005	0.001	--	--	0.01	0.022	0.001

The die is divided into a heating and a cooling zone. With the different die temperatures, the cooling rates differ in different regions. Therefore, different mechanical properties can be achieved in different zones throughout the specimen. The parameters used in this method are shown in Table 2.

Table 2 Experimental process for tailored properties

Temperature in cooling zone[°C]	Temperature in heating zone[°C]	Blank heating temperature[°C]	Temperature holding time[s]	Holding pressure[MPa]
25	25	930	300	18
25	200	930	300	18
25	300	930	300	18
25	400	930	300	18

Another method to get tailored properties is annealing the hardened specimen. The annealing temperature was set at 700, 740, 780 and 880 °C and induction heating was chosen. The Vickers Hardmeter 4630SVD was used to test the hardness distribution and the universal tensile testing machine AG-IC 100kN was used to test the tensile strength and total elongation in different regions.

2.2. Tooling development and methods

Dividing the die into a heating zone and a cooling zone (die partition) is one of the methods to get tailored properties, as shown in Fig. 1(a).When the hot blank is quenched in a die, its thermal resistance mainly relies on temperature difference during the heat exchange process between the blank and the die, thus affecting the cooling rate of the blank. When a hot blank is contacted with a cold die, the cooling rate will be so large that austenite will be completely converted into high-strength martensite, resulting in high strength parts. However, when a hot blank is in contact with a hot die, the thermal contact resistance increases, the cooling rate of the component will be reduced or even lower than the critical cooling rate (27 °C /s), beyond which the austenite transforms into martensite. Therefore, multi-phase microstructure comprising bainite and martensite is obtained with the reduced strength and enhanced plasticity.

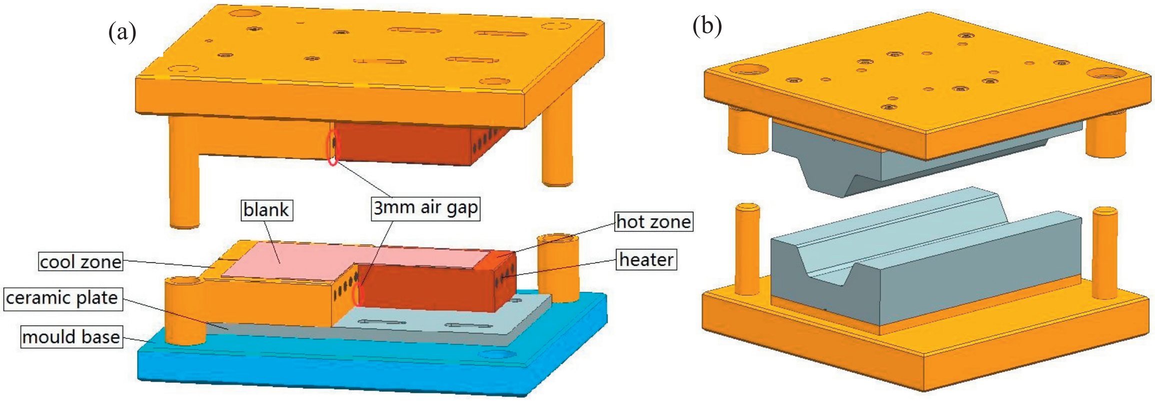

Fig. 1. Dies for tailored properties: (a) die partition; (b) die for stamping annealing parts

Annealing the hardened steel to obtained tailored properties is also an effective way in which martensite can be decomposed to other phases such as ferrite and carbides. Annealing experiments have been performed to determine the optimal annealing conditions. To avoid the bucking deformation after annealing, the U type part has been chosen which stamped by the die in Fig. 1(b). Heating temperature and time were determined to produce sound product.

3. Results and discussions

3.1. Results of dividing the die into heating and cooling zones

Fig. 2 shows the hardness distribution of the heating zone, the cooling zone and the transition zone at different temperatures. The hardness was tested by 430SVD Vickers Hardmeter. Each hardness data represents an average of three through-width measurements.

When the die temperature in the heating zone was below 400 °C, the minimum hardness value emerged in the transition zone. When the die temperature reached 400˚C, the higher hardness in cooling zone gradually transited to the lower hardness in heating zone, which coincides with the results of others [9]. When the die temperature in heating zone was below 200 ˚C, the hardness in the heating zone failed to decline significantly, which stayed at 500HV as well as the cooling zone. When the die temperature rose to 300 ˚C, the hardness in the heating zone declined from 500 HV to 450 HV. When the die temperature rose to 400 °C, part hardness in the heating zone was reduced to as low as 325 HV. The heat convection between blank and air in the transition zone results in the lower cooling rate, whose cooling performance is worse than that of contact heat transfer. What's more, the temperature of the air gap is affected by the die in the heating zone, which will be greatly improved, thus reducing the cooling rate in the transition zone. Considering the two factors, the lowest hardness value occurred in the transition zone. However, when the die temperature rises to 400 °C, the temperature difference reduces and the cooling rate in the heating zone is lower than that of transition zone.

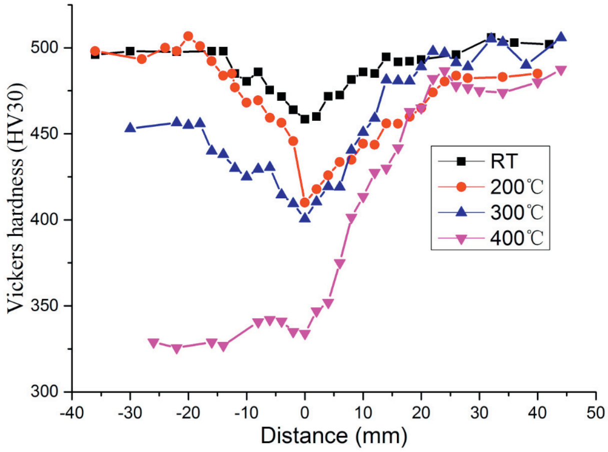

Fig. 2. Hardness results across the transition zone at different die temperatures

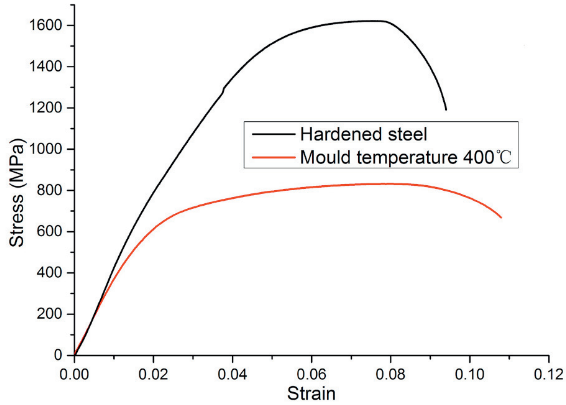

Fig. 3. Tensile curves of hardened steel and heating zone

Fig. 3 shows the strain-stress curves of the hardened steel in the cooling zone and the softened steel in the heating zone with die temperature of 400 °C. The tensile strength of the hardened steel reaches 1621 MPa, while the total elongation is only 9.4%. With the die heated to 400 °C, the tensile strength of heating zone reduces to 825 MPa and the total elongation rises to 10.8%. In conclusion, by the method of die partition to obtained tailored properties, the tensile strength declines obviously while the total elongation fails to increase significantly.

3.2. Results of annealing of hardened steel

Fig. 4 shows the physical map of annealed part and Fig. 5 shows the hardness distribution across transition zone at different annealing temperatures.

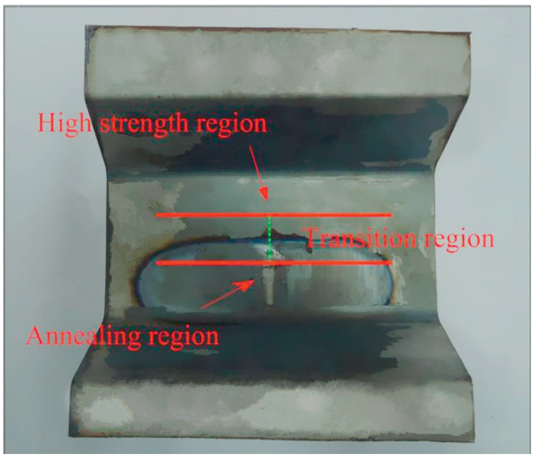

Fig. 4. Physical map of annealed part

With four different annealing temperatures utilized, the higher hardness in high strength zone gradually transited to the lower hardness in annealing zone. The hardness in annealing zone is bellow 250HV, no matter how much the annealing temperature is. From the hardness distribution curve, it has been found that annealing temperature has little effect on the hardness value. The annealing zone reaches its lowest hardness value at the annealing temperature of 780 °C, indicating that the hardness does not decrease with the rise of annealing temperature.

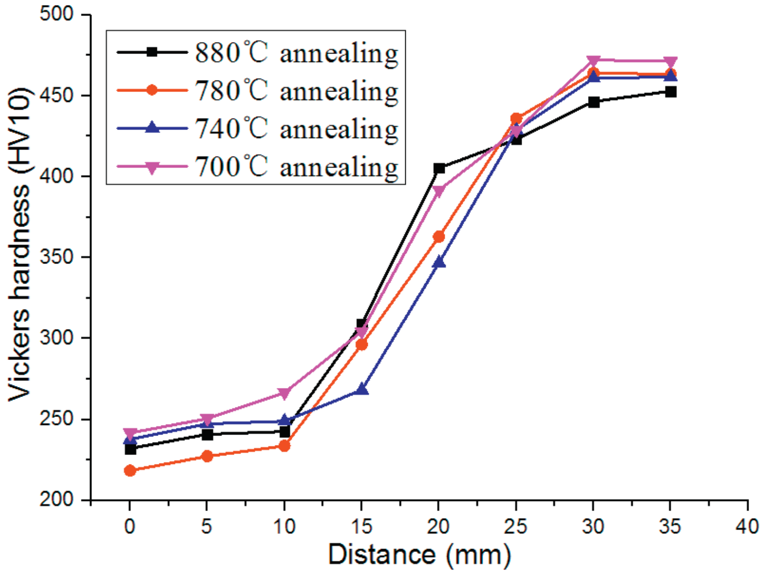

Fig. 5. Hardness distribution across the transition zone at different annealing temperatures

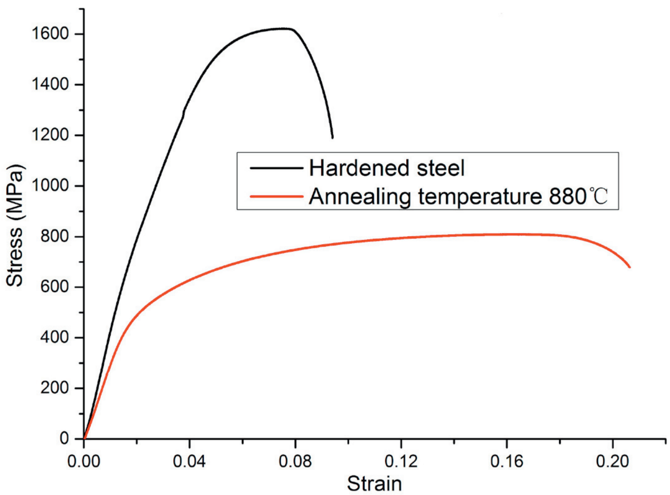

Fig. 6. Tensile curves of hardened steel and annealed part

Fig. 6 shows the tensile curves of hardened steel and annealed part. The total elongation of annealed part reaches 20.6% while the tensile strength decreases to 805 MPa. Compared to the results of die partition shown in Fig. 2 and Fig. 3, the method of annealing to obtain tailored properties brings about better performance. However, annealing the hardened part to get tailored properties needs an additional process which is disputed in industrial community.

4. Conclusions & future work

In order to enhance the crashworthiness, energy absorption of the whole component as well as the safety performance, this work has performed hot stamping of high strength steel with tailored properties by two methods. Dividing the die into a heating zone and a cooling zone (die partition), the obtained results distinguish with that reported in the current literatures, which needs to be investigated in the future work. Meanwhile, the following basic disciplines can be concluded from the obtained results: (1) When the die temperature is lower than 300°C, the hardness reaches its minimum value in the transition zone, while when the die temperature exceeds 400°C, the hardness exhibits gradient transition from the cooling zone to the heating zone; (2) By the method of annealing, the hardness gradiently changes from high strength zone to annealing zone and the annealing temperature shows little influence on the hardness distribution; (3) Regardless of the decrease of tensile strength, the total elongation of annealed zone can reach 20.6% while the part in the heating zone can only obtain 10.8%. The results show that the method of annealing hardened part to get tailored properties achieves better performance.

In the future, corresponding experiments and numerical research will be carried out to investigate the complex hardness distribution and find solution to get better performance with tailored properties.

Acknowledgements

This work was financially supported by the National Natural Science Foundation of China (51275185), Graduate Innovation and Entrepreneurship Fund of Huazhong University of Science and Technology (HUST, No. 0109070112), and the Fundamental Research Funds for the Central Universities (HUST, No. 0118110621).

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